STRUCTURE AND MINERALIZATION OF THE ORO BLANCO MINING DISTRICT, SANTA CRUZ COUNTY, ARIZONA

by

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I hereby recommend that this dissertation prepared under my direction by Louis Harold Knight, Jr.

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Evans B. Mayo	October 20, 1969
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*This approval and acceptance is contingent on the candidate's adequate performance and defense of this dissertation at the final oral examination. The inclusion of this sheet bound into the library copy of the dissertation is evidence of satisfactory performance at the final examination.

STATEMENT BY AUTHOR

SIGNED: Louis Harold Knight, Jr

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ABSTRACT

The Oro Blanco mining district, Santa Cruz County, Arizona, is underlain by a succession of Mesozoic rocks that has been tilted southwestward and repeated by large displacement northwest-striking normal faults. The Mesozoic rocks include over 12,000 feet of Jurassic(?) rhyolite and quartz latite ash flow tuffs and waterlain tuffs. These are unconformably overlain by at least 5,900 feet of Lower Cretaceous(?) terrestrial sedimentary rocks.

Two types of plutonic rocks have been recognized as Mesozoic in age, equigranular quartz monzonite stocks of Jurassic(?) age and a hornblende diorite sill of Middle or Late Cretaceous age.

A nearly horizontal mantle of Tertiary rocks covers the eastern part of the Oro Blanco mining district. This is composed of a sequence of Lower Tertiary andesite to dacite flows and pyroclastics that is unconformably overlain by rhyolite flows and tuffs of Oligocene age. The youngest rock unit in the district is a poorly indurated sequence of interbedded gravels and waterlain tuffs.

The principal structural features are normal faults of large displacement having three dominant strikes, north-northeast, northeast, and northwest faults formed in Jurassic(?) time whereas the others did not form until Late Cretaceous to Early Tertiary time, during the Laramide orogeny.

The structurally most important direction of faulting is northwest. Northwest striking, northeast-dipping normal faults commonly have large displacements in the range of 6,900 to 11,000 feet. These have caused extensive repetition of the southwestward-dipping Mesozoic stratigraphic units throughout western Santa Cruz County and south-central Pima County, Arizona.

Compilation of structural data for Paleozoic and Mesozoic rocks in Pima and Santa Cruz Counties indicates the presence of a large northwest-trending collapse structure about 100 miles in width that was caused by an average crustal extension of 25 percent during the Laramide orogeny. This extension may be related to crustal spreading away from the crest of the East Pacific rise if it passes beneath the Basin and Range Province of Arizona.

Mineralization in the Oro Blanco mining district is in quartz-sulfide veins, silicified zones, and breccia veins. Base and precious metals have been produced from the quartz-sulfide veins, whereas only precious metals have been produced from the silicified zones and the breccia veins. The mineralization is of hydrothermal origin and ranges from mesothermal to epithermal in environment of deposition.

The mineral deposits have been localized in dilational zones in and adjacent to large displacement faults. Intersection of northwest faults and northeast cross faults may have localized some oreshoots. The basal conglomerate of the Lower Cretaceous(?) sedimentary rocks seem to be a favorable host rock.

District zoning of the quartz-sulfide vein compositions suggests that a center of mineralization may lie beneath the cover of post-mineralization Tertiary rocks east of the Oro Blanco mining district. Except for possible economic mineralization beneath this cover, the future economic potential of the district is very poor.

INTRODUCTION

Purpose and Scope

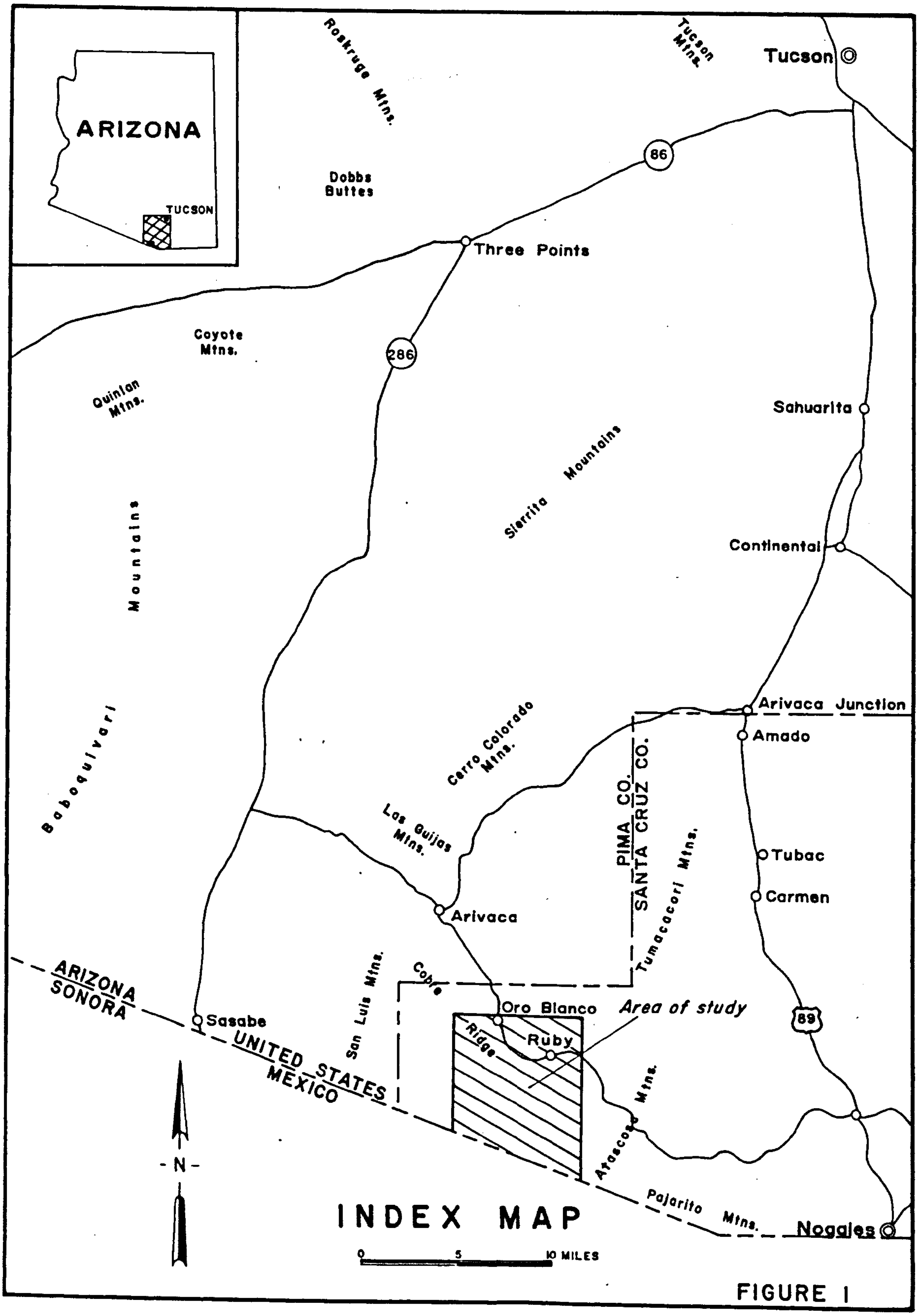
The purposes of this investigation are to determine the structural and mineralization history of the Oro Blanco mining district, Santa Cruz County, Arizona, and to use this information to decipher the structural development of a large part of southern Arizona.

The report includes description and discussion of the stratigraphic and intrusive relationships, district and regional structure, and the nature and distribution of mineralization. A possible site for undiscovered mineralization is suggested.

Location and Accessibility

The area of investigation includes approximately 40 square miles in the Oro Blanco Mountains of western Santa Cruz County, Arizona (Figure 1). It lies about 6 miles southeast of the village of Arivaca, mainly in the southeastern fourth of T 22 S, R 10 E, the eastern half of T. 23 S, R 10 E, the southwestern fourth of T 22 S, R 11 E, and the western half of T 23 S, R 11 E. The area is bounded on the south by the International Boundary, on the west by a pediment, and on the east by Mule Ridge. The only settlements are Oro Blanco and the now abandoned Ruby mining camp.

The area is accessible from an improved gravel road connecting Arivaca, Ruby, and Nogales. Several good, unimproved trails extend into


ARIZONA
TUCSON
Roskruge Mtns.
Tucson Mtns.
Tucson
86
Dobbs Buttes
Three Points
Coyote Mtns.
286
Quinlan Mtns.
Sahuarita
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Amado
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Las Guijas Mtns.
PIMA CO.
SANTA CRUZ CO.
Tumacacori Mtns.
Tubac
Carmen
Arivaca
Cobre
ARIZONA
SONORA
Sasabe
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Oro Blanco
Area of study
Ruby
Ridge
89
UNITED STATES
MEXICO
Atascosa Mtns.
N
Pajarito Mtns.
Nogales
INDEX MAP
0 5 10 MILES

FIGURE 1

the Oro Blanco district, most of which are passable in a standard pickup truck or other vehicle having sufficient ground clearance. Four-wheel drive is recommended for the trail on the south slope of Bartlett Mountain and the trail to Cobre Mountain.

Summary of Physical Features

The Oro Blanco Mountains lie in the southern part of the Basin and Range physiographic province of Arizona which in general is characterized by narrow northwest-trending ranges and relatively wide intervening alluvium-filled valleys. The Oro Blanco Mountains may be considered as typical of the province in that they, too, have a northwest direction of elongation. The elongation of the ranges is generally considered to reflect the orientation of structures developed during the mid-Tertiary Basin and Range orogeny, but data from this investigation suggest that the northwest trends of the Oro Blanco and neighboring Pajarito and Las Guijas ranges were developed in the late Cretaceous to early Tertiary Laramide orogeny.

The Oro Blanco Mountains could be described as tilted fault-blocks in which normal faulting has been the dominant means of rock failure.

Elevations range from 5,370 feet at Montana peak to about 3,600 feet along the Mexican border south of Bartlett Mountain. The maximum local relief in the district is 1,200 feet at Montana peak. Elsewhere the relief is rarely over 500 feet.

Vegetation is typical of the semiarid southwest upper Sonoran zone where rainfall averages about 14 inches per year. It consists of Gambel oak, various grasses, desert shrubs, and sparse cacti.

Most of the streams are ephemeral, flowing only during the rainy seasons in mid-summer and mid-winter. Certain parts of California gulch, however, near the Mexican border, flow most of the year. The principal drainages for the area are California gulch, Warsaw Canyon, and Holden Canyon, which flow southwards; Oro Blanco wash, Chimney Canyon, and Yellow Jacket wash which flow northwards.

Field and Laboratory Work

Approximately 14 months were spent in the field. The mapping was started in April, 1968, and completed June, 1969, during which time an average of about 3 days per week was spent in the field. U. S. Forest Service aerial photos at a scale of 4 inches = 1 mile were used as a base for mapping. Data were transferred to the U. S. Geological Survey Oro Blanco and Ruby quadrangle topographic maps enlarged to a scale of 4 inches = 1 mile. Photogeologic interpretation proved very helpful in tracing out many of the rhyolite dikes in the northwest-striking swarm and for spotting many of the major faults prior to their actual recognition in the field. Such interpretation yielded much general information on the distribution of rock units that led to more efficient use of field time. In addition to mapping in the Oro Blanco district, a small amount of regional mapping and field checking of previously studied areas was undertaken to aid in explaining the geology. A limited amount of assaying was done at various mineral showings in the district in order to evaluate the precious metal mineralization.

Laboratory work consisted of examining 87 thin sections from the Oro Blanco mining district and the neighboring Pajarito, Las Guijas, and Cerro Colorado Mountain areas. Twenty-four polished sections from several of the mineral showings were examined and gold fineness values on panned samples were determined in an effort to establish the mineral zoning pattern in the district.

Previous Investigations

The earliest work in the district is by Blake(1899) in which a few notes on the gold mineralization appear. Some of the rock types present in the Oro Blanco district are shown on the Pima and Santa Cruz County Geologic map of the Arizona Bureau of Mines (Wilson, Moore, and O'Haire 1960), but no detailed geology of the district as a whole has previously been published. Webb and Coryell(1954) published a photogeologic map and brief report on the Ruby quadrangle in which they describe two Tertiary volcanic units, the Montana Peak Formation and the Atascosa Formation. They also propose the name Pajarito lavas for a thick sequence of Mesozoic volcanic rocks and recognize the unit both in the Pajarito Mountains and in the Oro Blanco district near Ruby. They did not attempt to work out the structure in the Mesozoic rocks but simply state that it is complex.

Reed(1967) studied the geology of the Fraguita Peak area which adjoins on the north the area described in this report. Reed feels that the quartz latite volcanic rocks of the Cobre Ridge tuff in the present area of study are intrusive into the Oro Blanco conglomerate. He explains the presence of quartz latite cobbles in the conglomerate by stating that the conglomerate is a sedimentary rock that was remobilized by the intrusive quartz latite. The conglomerate incorporated the quartz latite boulders during remobilization. Data gathered during the present investigation show that the conglomerate lies on an erosional surface developed on the quartz latite and that faulting (not observed by Reed, but plainly evident) accounts for the distribution of rock units shown on Reed's map.

Nelson(1963) studied the Peña Blanca and Walker Canyon areas about 8 miles southeast of the Oro Blanco district. He describes many of the same units as the present author and finds the conglomerate to be younger than the quartz latite "lavas" and in depositional contact. The unit termed the Pajarito lavas by Nelson, the correlative of the Cobre Ridge tuffs, is actually a sequence of firmly indurated ash flow tuffs, both welded and nonwelded.

Hench(1968) conducted a regional gravity survey over much of the Ruby quadrangle and the eastern part of the Oro Blanco quadrangle that indicates a large negative regional Bouguer gravity anomaly east of the Oro Blanco district.

GENERAL GEOLOGY

Rocks exposed in the Oro Blanco mining district (Figure 2) range from Jurassic(?) to Tertiary in age. Much of the district is underlain by a sequence of quartz latite and rhyolite tuffs of Jurassic(?) age which comprise a total thickness of over 12,000 feet. A significant part of the sequence consists of welded ash flow tuffs. The name Cobre Ridge tuff is proposed for this volcanic sequence. Intrusive into the volcanic rocks, but not into any younger units, is an equigranular quartz monzonite. The quartz monzonite occurs as stocks that have been offset by faulting.

Unconformably overlying the Cobre Ridge tuff and quartz monzonite is a sedimentary sequence termed the Oro Blanco Formation. This unit is probably early Cretaceous in age. It consists of at least 5,900 feet of conglomerate, sandstone, siltstone, and limestone. This formation has a thick basal conglomerate that has been referred to in the past as the Oro Blanco Conglomerate (Fowler 1938).

A sill of Cretaceous(?) hornblende diorite, the Ruby diorite, intrudes the Oro Blanco formation near its base. This sill reaches a maximum thickness of about 2,500 feet.

Southwestward tilting and large displacement normal faulting preceded the emplacement of the rocks younger than the Ruby diorite. The earliest faults have a north-northeast strike and are downthrown

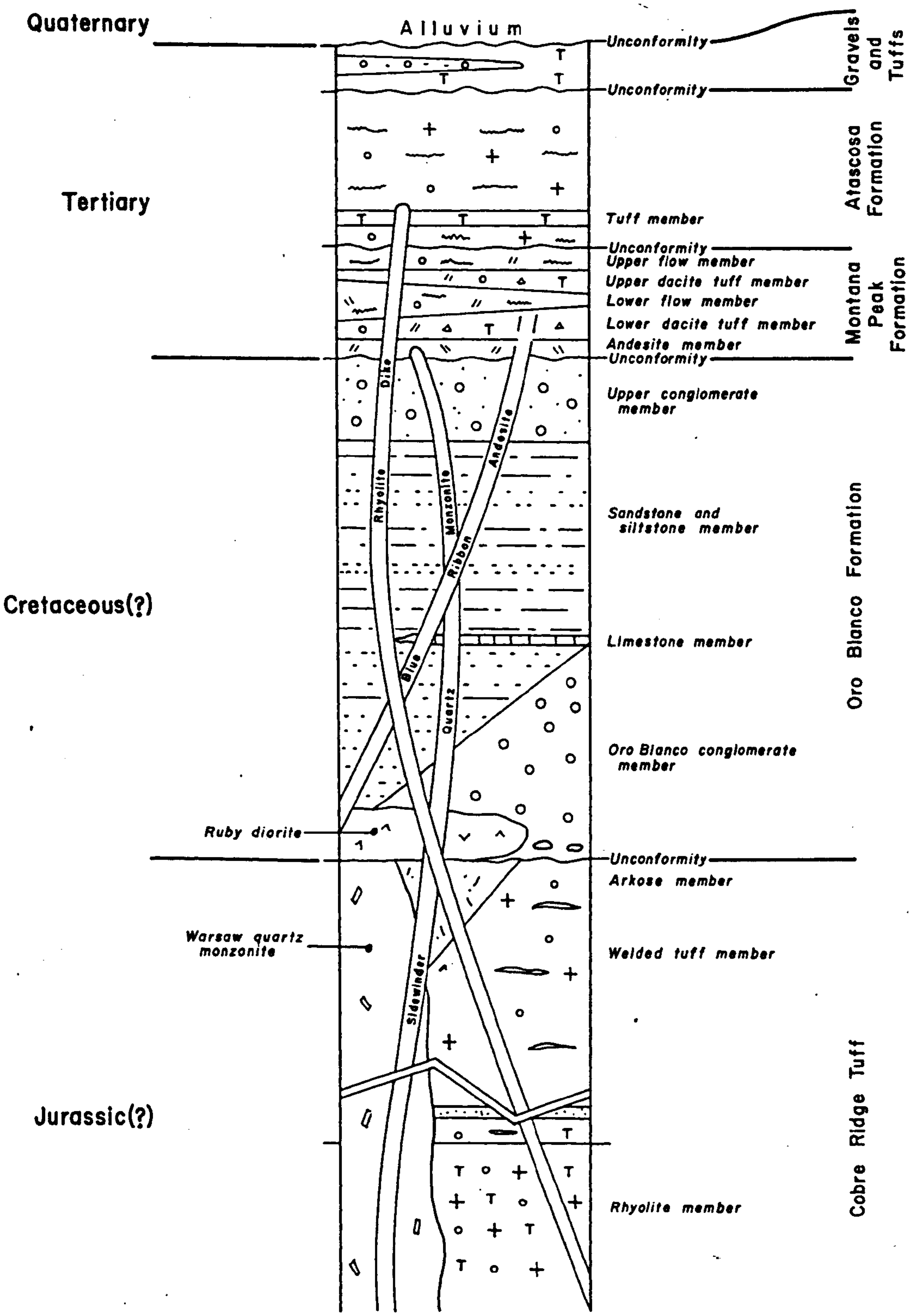


Figure 2. Stratigraphic Column

on the east side. Some of these were active even before the deposition of the Oro Blanco formation. A few faults having a northeast strike then formed, one of which may have over 10,000 feet of displacement. Similarly, large displacements are recorded on the next younger set of faults, those which strike northwest. The northwest-striking faults are normal faults which are downthrown on the northeast side, so that they have caused extensive repetition of the stratigraphic section. Last of all, renewed movements took place on the northeast-striking faults which offset the northwest-striking faults.

All three directions of faulting have served as loci for precious and base metal mineralization. Mineralization occurred after the major movements on the three directions of faulting but before emplacement of Tertiary Sidewinder quartz monzonite dikes.

The mineralization consists of three main types; quartz-sulfide veins, flat-dipping silicified blankets having sulfide minerals, and mineralized breccia zones. The minerals of greatest economic importance in the district are sphalerite, galena, chalcopyrite, tetrahedrite, native gold, native silver, and cerargyrite-bromyrite.

Sidewinder quartz monzonite of Tertiary age intrudes much of the district as flat-dipping dikes and irregular shaped masses. Some of this rock may be extrusive.

In part contemporaneous with the Sidewinder quartz monzonite is a sequence of andesite and dacite flows and pyroclastics, the Montana Peak Formation, which overlies the Mesozoic rocks with pronounced angular unconformity. The Montana Peak Formation is overlain disconformably by the Oligocene Atascosa Formation which consists of 1,800 feet of rhyolite flows and tuffs.

A large swarm of rhyolite dikes considered to be the feeders for the Atascosa Formation lies in a northwest-trending belt in the southern part of the Oro Blanco district.

Erosion of the Atascosa Formation has produced a sequence of interbedded, poorly cemented gravels and tuffs that are probably Late Tertiary in age.

In Recent time unconsolidated gravels have been deposited on a pediment area and along stream courses throughout the Oro Blanco mining district.

SEDIMENTARY AND VOLCANIC ROCKS

Stratified rocks in the Oro Blanco mining district are composed of a lower sequence of volcanic rocks, an intermediate sequence of sedimentary rocks, an overlying sequence of volcanic rocks, and an upper sequence of poorly consolidated sedimentary rocks. These units range in age from Jurassic(?) to Tertiary. The Jurassic(?) rocks total over 12,000 feet in thickness; the Cretaceous(?) rocks, nearly 6,000 feet; and the Tertiary rocks about 3,500 feet.

Jurassic(?) Rocks

Cobre Ridge Tuff

Cobre Ridge tuff is a new formation name proposed for a thick succession of quartz latite and rhyolite tuffs of Jurassic(?) age. The only previous work on this unit is by Reed(1967) who feels that it is a shallow, flat-lying intrusive body for which he proposes no name except Tertiary(?) quartz latite. The formation is named for Cobre Ridge, a major northwest-trending ridge in the Oro Blanco district which is underlain mainly by this unit.

Cobre Ridge tuff underlies considerably more than half of the Oro Blanco mining district. It is exposed as rounded, steep-sided, northwest-trending ridges in the north, west, and southwest parts of the district.

The Cobre Ridge tuff consists of three members, the rhyolite member, a lower member of non-welded rhyolite tuffs and minor welded quartz latite tuff; the welded tuff member, consisting mostly of weakly to strongly welded porphyritic quartz latite tuff; and the arkose member, an upper member consisting of fine-grained arkosic sandstone and arkose. These three members comprise a total thickness of at least 12,400 feet. The lower contact of this formation is a fault, and the base is nowhere exposed within the Oro Blanco district. The unit is overlain with local angular unconformity by the lower Cretaceous(?) Oro Blanco formation.

Rhyolite Member. The rhyolite member is principally exposed on the northeast slope of Cobre Ridge (Figure 3) and near the Margarita mine. It also underlies a considerable area on the southwest slope of Cobre Ridge where it has been repeated through large displacement faulting, but exposures here are poor and few in number. The member consists of at least 6,700 feet of rhyolite tuffs and relatively minor interbedded quartz latite welded and non-welded ash flow tuffs. The lower contact of the rhyolite member is a fault which brings it into contact with the overlying welded tuff member. The rhyolite member is conformably overlain by the welded tuff member.

Rhyolite tuff is the principal lithologic type in this member. This rock weathers light yellowish tan and forms highland areas having deeply incised, steep-walled drainage. The individual outcrops are generally strongly fractured by at least three intersecting joint sets so that the rock readily splits into small prisms one to four inches on a side. In hand specimen the rock has a dense, firmly indurated, greenish-gray aphanitic groundmass and very distinctive purplish-pink

BLK
TOURMALINE

potash feldspar phenocrysts 2 to 3 mm in length. Most of these are but phenocryst fragments. In addition, broken angular phenocrysts of dark-gray quartz and white altered plagioclase are common. Mafic minerals are scarce in this rock, but veinlets of black tourmaline are common especially near bodies of Warsaw quartz monzonite. Perhaps the most distinctive feature of this rock is the potash feldspar which has a definite violet coloration that has been observed only in this unit.

In thin section the nature of the aphanitic matrix becomes clear. It consists of well-sorted, fine-grained subangular quartz and feldspar grains which average about .1 mm across. This matrix seems to be of sedimentary origin. Scattered throughout the matrix are many crystal fragments composed of embayed quartz, sanidine and sericitized plagioclase. These larger fragments are virtually unsorted. Rarely an alignment of grains will suggest depositional bedding. Point counting of 3 thin sections from different levels within the unit yields the following modal compositions:

Quartz phenocrysts	10%	5%	17%
Sanidine phenocrysts	40	22	20
Plagioclase phenocrysts	2	9	7
Miscellaneous	<1	<1	1
Matrix (quartz and K-feldspar)	48	64	55

The good sorting of the matrix of this rock indicates probable transportation by running water, but the angularity of the crystal fragments suggests that the distance of transport was not great. It is suggested that much of the rhyolite member is a waterlaid tuff formed from reworking of crystal-rich volcanic ash.

Interbedded with the rhyolite tuffs are welded ash flow tuffs of quartz latite composition. These lie near the base of the member and are best exposed on the west slope of Black Peak. This rock was noted in the course of the field work, but has not been mapped separately from the rhyolite member. At Black Peak it is probably several hundred feet in thickness, but wedges out along strike to the southeast. To the northwest it has been faulted out of view. The welded tuffs have a pinkish-brown aphanitic groundmass with a few scattered phenocrysts of quartz, pink potash feldspar, and greenish-altered plagioclase that average 2 to 4 mm in length. Most exposures examined by the author have a faint eutaxitic structure, but large flattened inclusions and pumice lumps are rare in this rock.

The rhyolite member generally has poorly developed bedding that requires careful examination of outcrops in order to find measureable attitudes. The bedding in this unit usually strikes northwest or north-northwest and dips 60 to 70° southwest.

Welded Tuff Member. The welded tuff member occupies much of the crest of Cobre Ridge and the hills just to the east of Oro Blanco settlement. Relatively small areas on the southwestern slope of Cobre Ridge are underlain by this unit as well. A slice of this unit caught between two major faults lies along the northeastern slope of Cobre Ridge between the Montana mine and the Yellow Jacket mine. This member consists of a maximum of 5,700 feet of welded and non-welded quartz latite tuffs, and minor interbedded arkosic sandstone that reaches a thickness of slightly over 300 feet. A crystal rich non-welded quartz latite tuff makes up the lower 1,300 feet of the welded tuff member. This rock is a dense, firmly-indurated tuff having a dark-gray, aphanitic matrix and many crystal fragments of embayed quartz, sanidine, and sericitized plagioclase. A small amount of chloritized biotite comprises about 2 percent of the rock. Quartz, sanidine, and plagioclase phenocrysts 2 to 4 mm in length are in about equal abundance and total nearly 40% of the rock.

Excellent exposures of this crystal-rich tuff lie on the west side of Chimney Canyon and in Old Glory Canyon northwest of the Old Glory Mine. In various faulted parts of the welded member in the southwestern part of the district this crystal rich tuff is absent. Here strongly welded tuffs directly overlie the Rhyolite member.

Conformably overlying the crystal-rich tuff in the northern and central parts of the area of study is a thin arkosic sandstone unit or a zone of interbedded sandstones and tuffs. The sandstone units consist of fine-grained, cross-bedded arkosic sandstone, ranging from light tan through orange to deep red-brown. The sand grains are very well rounded and have a frosted appearance suggesting wind transport. Similar fine-grained arkosic sandstone units have been found higher in the welded tuff member but these are very lensy and rarely reach over 20 feet in thickness.

The upper part of the welded tuff member consists almost entirely of ash flow tuffs having various degrees of welding. No serious attempt has been made in this study to distinguish between individual cooling units in the ash flow sequence. But the presence of the interbedded sandstone lenses as well as examination of several thin sections from samples on traverses across the welded tuff member suggest that at least three cooling units make up the 5,400 feet of ash flow tuffs. It is very probable that more exist but have not been recognized.

In outcrop the rocks of the upper part of the welded member are commonly badly shattered by several intersecting sets of joints. A peculiar flat-dipping, but undulating joint system characterizes many of the outcrops just north of the Warsaw mine. The joints are spaced about 1 to 2 inches apart and undulate across the outcrop giving the superficial appearance of small folds. These structures are not related to the foliation in the tuff which dips nearly the same throughout the area and at large angles to the undulating joints. This type of jointing seems to be best developed in the more strongly welded areas. The outcrops weather to various shades of gray, but on a fresh surface the coloration is much different, usually a pinkish purple or dark brownish red.

In hand specimen the rock is seen to consist of a pinkish-purple, light to medium gray, or dark brownish red, dense, aphanitic matrix and a widely ranging number of phenocrysts of quartz, sanidine, and plagioclase usually in the size range of 1 to 4 mm. In some of the strongly welded specimens eutaxitic structure is plainly visible although the fiamme are generally small, rarely over 1 centimeter in length.

Much of the welded tuff shows no evidence of welding in hand specimen, but welding is plainly indicated by the abundant flattened devitrified glass shards visible under the microscope. Lithic fragments are sparse in most of the welded tuff member.

In thin section the rock is composed of a devitrified microcrystalline matrix rich in cristobalite and potash feldspar. In plain polarized light the matrix resolves into many shard outlines in various degrees of flattening depending upon what part of the welded tuff member is being examined. Phenocrysts consist of embayed and broken quartz, broken sanidine and andesine, and a small amount of fine-grained biotite. The modal composition based on an average from point counting 12 thin sections taken from various levels in the member is given below along with the range of variations observed:

Quartz phenocrysts	10%	4 to 18%
Sanidine phenocrysts	10	4 to 19
Andesine phenocrysts	10	4 to 11
Biotite	2	<1 to 4
Groundmass	68	54 to 87

Nearly all thin sections of this unit examined by the writer are slightly altered. Andesine has been partly replaced by sericite and the biotite has generally been replaced by chlorite and magnetite. Sanidine and the groundmass are generally unaltered.

The foliation, that is, eutaxitic structure generally strikes northwest or north-northwest and dips steeply or moderately southwest although some slight overturning has occurred locally.

Arkose Member. The arkose member is exposed in the extreme southwestern part of the Oro Blanco district and possibly in the western part. This member conformably overlies the welded tuff member and may be overlain by Oro Blanco formation. An exposure that may belong to this member but whose characteristics differ considerably from the main exposures of the arkose member lies in the western part of the district. At this point it is overlain conformably by Oro Blanco formation. In the southwestern part of the district where the main body of the arkose member is exposed the top of the section has not been seen, for it lies south of the International Boundary. The greatest thickness of this member is about 2,600 feet, but judging from its presence in only a small part of the district it probably was deposited in a fairly deep basin of small lateral extent. This maximum thickness may thus be somewhat misleading.

Exposures of the arkose member weather to low, rounded hills which have their drainage controlled by bedding planes. The rock in hand specimen is a yellowish tan medium to fine grained arkose or arkosic sandstone. The rock is firmly indurated and has indistinct bedding so that locally it is difficult to decide in hand specimen whether it is an arkose or a granite. The grains are very well sorted in general, but sparse thin lenses of coarser or finer grains enable one to recognize the attitude of bedding.

In the western part of the studied area several hundred feet of arkosic sandstone overlie the welded tuff member. Although it is at a position in the stratigraphic section similar to the arkose member its characteristics are different. This unit consists of a tan to dark red brown, fine-grained arkosic sandstone that more closely resembles the sandstone lenses within the welded tuff member than it does the arkose member. For this reason the writer has included this rock within the welded tuff member.

Cretaceous(?) Rocks

Oro Blanco Formation

The name Oro Blanco formation is proposed here for a sequence of Lower Cretaceous(?) sedimentary rocks consisting of a basal conglomerate and overlying beds of sandstone, siltstone, and minor limestone. The formation includes the previously named Oro Blanco Conglomerate (Fowler 1938) as its basal member. This redefinition is necessary because of the extreme variability in the thickness of the conglomerate, its genetic relationship to the overlying finer-grained sedimentary rocks, and the complex interfingering of conglomerate and the fine-grained beds.

The Oro Blanco formation is subdivided into four members; a basal conglomerate, the Oro Blanco conglomerate; a thick sequence of interbedded sandstones, pebbly sandstones, and siltstones; a thin but laterally persistent black limestone member; and a second conglomerate, termed the upper conglomerate member.

Oro Blanco Conglomerate Member. The original name Oro Blanco Conglomerate was proposed in 1938 by G. M. Fowler for a thick succession of coarse conglomerates at the Montana mine. Fowler gave the following description for the unit, p. 44:

> " The conglomerate is characterized by the angularity and the coarseness of its constituent fragments. It seems difficult to classify this rock, as it combines characteristics of a conglomerate and a breccia. The fragments range between an inch and 12 inches in diameter. Small gravel is present only in sufficient quantity to fill the interstices. The color is reddish and grayish, with some dark-hued, greenish fragments that give the mass a varigated appearance in some places."

In addition to being exposed at the Montana mine, the conglomerate covers small areas throughout the Oro Blanco district. Complete sections of this member lie just south of the Montana mine, northwest of the Idaho mine, and in California Gulch near the Dos Amigos mine. Complete, but thin, sections of it are exposed one-half mile east of Oro Blanco settlement and at several other localities. In many areas the conglomerate section has been partially repeated by normal faults or swelled by the emplacement of a thick diorite sill.

Its original thickness ranges considerably throughout the district. Just south of the Montana mine it reaches the maximum thickness of 2,600 feet whereas in the area one and one-half miles south of the Yellow Jacket mine it is at most only a few feet thick, and locally is absent entirely.

The conglomerate lies on an erosional surface formed on the Cobre Ridge tuff. Locally a few degrees of angular discordance are visible. The conglomerate is conformably overlain by the upper two members of the Oro Blanco formation.

Exposures of the conglomerate are very resistant to erosion and tend to form hills and ridges having rounded tops but steep sides.

Individual outcrops appear very rubbly with dark coloration, generally dark purplish-gray or pinkish-gray. The rock consists dominantly of subangular to rounded pebbles, cobbles, and boulders of Cobre Ridge tuff almost to the exclusion of other rock types (Figure 4). In the east, however, particularly just south of the Montana mine, cobbles and boulders of medium to coarse-grained equigranular quartz monzonite are abundant. A few of these boulders are over six feet in length. These fragments are virtually identical in composition to the Warsaw quartz monzonite, especially the body exposed in the southwestern part of the mapped area. The only other rock types observed in the conglomerate are very sparse fragments of quartzite and dark purple porphyritic andesite.

Striking vertical variations are evident in much of the conglomerate. At the base the rock consists entirely of coarse brecciated Cobre Ridge tuff having little or no finer grained matrix. The volcanics are noticeably reddened for several feet below the contact. As one progresses upwards the degree of rounding increases and the rock obtains an arkose matrix. The matrix consists of poorly sorted subangular sand and fine gravel derived from the Cobre Ridge tuff. Higher in the section the percentage of matrix increases and the size of the coarse fragments decreases, so that the conglomerate grades into the overlying sandstones.

The quality of bedding likewise varies with the position in the section. At the base it is generally very difficult to see bedding attitudes, but higher in the section they are plainly visible especially

Figure 4. Oro Blanco Conglomerate Member

Note poorly sorted subangular fragments composed mostly of Cobre Ridge tuff and fine sandy matrix.

where thin, sandy units are interbedded with the conglomerate. Unusually coarse boulder conglomerate such as that south of the Montana mine generally lacks bedding.

The Oro Blanco conglomerate was deposited upon a surface of considerable relief. About 1,000 feet southwest of the junction of the Ruby and California Gulch roads a channel has been cut into the Cobre Ridge tuff to a depth of about 700 feet and filled with conglomerate. Here the lowermost 100-200 feet of the conglomerate consists of brecciated tuffs with little or no reworking. This is overlain by the more usual poorly sorted conglomerate. Another area where great relief is shown on the base of the unit is in the patch of conglomerate just east of the Yellow Jacket mine. Here steeply dipping conglomerate fills a narrow nearly east-west depression in the erosional surface which seems to be about 150 feet deep.

In summary the significant features of the Oro Blanco conglomerate are:

1) It was deposited upon a surface of high relief.
2) It is generally very poorly sorted.
3) Its thickness ranges widely over short strike lengths.
4) Except near the Montana mine it is virtually oligomictic.

Sandstone and Siltstone Member. This unit conformably overlies the conglomerate member and near its base is extensively interbedded with the conglomerate. The sandstone and siltstone member underlies most of the lowlands near Oro Blanco village. Many faulted exposures lie in the southeast part of the mapped area. A considerable thickness of this unit is exposed on the southwest slope of Cobre Ridge in the northwest part of the mapped area. In addition the lowlands along the Arivaca to Ruby road northwest of the mapped area are underlain mostly by this member.

The unit consists of at least 5,600 feet of maroon, brown, and green siltstone, sandstone, and pebbly sandstone (Figure 5). This member is characterized by poor sorting, abundant cut and fill, and graded bedding. Lenses of poorly rounded and poorly sorted gravel are commonly interbedded with siltstone and sandstone.

According to the classification of Pettijohn(1957) the sandy units would be classified as lithic graywacke and feldspathic graywacke. The detrital materials comprising the sandy beds are derived mainly from the Cobre Ridge tuff, although locally a few pebbles of andesite porphyry may be observed. The rock fragments generally are thoroughly oxidized so that their present color is deep red or maroon. It is these lithic fragments that give the rock its characteristic maroon color. Feldspar fragments, mainly sanidine, are abundant. The potash feldspar fragments are virtually unaltered but plagioclase fragments are generally well sericitized. The matrix of the sandstones is mainly clastic, but some silica cement is present as well.

The silty beds in this member are very similar in composition to the coarser clastics. They too consist mainly of oxidized rock fragments, detrital feldspar, and siliceous cement. These beds differ from the sandstones in their greater diversity of coloration. Although much of this unit is maroon, considerable amounts are green, brown, and dark gray, especially in the upper part of the member in the southeast portion of the mapped area. Northwest of the mapped area much of the upper part of this member is a green, thinly-laminated siltstone. On the eastern part of Figure 3 the sandstone and siltstone member contains a thin but laterally persistant black limestone unit, the limestone member.

Limestone Member. The limestone member is present only in the eastern part of the studied area. It consists of a maximum of 120 feet of thinly bedded black silty limestone, gray limestone, and sandy limestone which is conformable to the underlying and overlying clastic sedimentary rocks. In the extreme eastern exposures, the limestone member lies directly upon the Oro Blanco Conglomerate, but to the west a facies change in the underlying clastic rocks places the limestone upon beds of the sandstone and siltstone member. This unit is everywhere overlain by the sandstone and siltstone member.

The limestone member is very thin but persistant along strike. Although its maximum observed thickness is about 120 feet, its average thickness is probably about 20 to 30 feet. The limestone has been traced along strike in faulted segments for a distance of four and one-half miles. It is easily recognizable over this distance even though its details of composition vary somewhat.

To call this member a limestone is perhaps a misnomer. In general the unit contains a large portion of clastic material ranging from black silt and clay to cobbles of Cobre Ridge tuff. Where the clastic debris is very fine grained, the impure limestone is very

Figure 5. Interbedded Pebbly Sandstone and Sandstone

This material is characterized by exceedingly poor sorting. The fragments consist mostly of Cobre Ridge tuff.

thinly laminated; where the debris is coarse, the bedding is commonly very indistinct. In a few exposures the limestone resembles Recent caliche-cemented sand.

The coarse debris-rich limestone is not the most abundant variety, but is described here for its possible importance in the genesis of the unit. The dominant type is the thinly laminated black silty limestone and limy siltstone.

These beds are virtually devoid of any fossils. One small, but poorly preserved gastropod and a few carbonized wood fragments have been found, but neither is well enough preserved to identify.

Upper Conglomerate Member. A thick conglomerate unit overlies sandy and silty beds one half mile east of the Oro Fino mine and north of the Skyline mine. The conglomerate is very similar to the Oro Blanco Conglomerate but seems to be in depositional contact with underlying finer-grained clastics. It is overlain by more sandstones and siltstones in the southeast, and in fault contact with Cobre Ridge tuffs near the Skyline mine.

The conglomerate is virtually indistinguishable from the Oro Blanco conglomerate in most places, but locally contains a few distinctive dark-green andesite fragments of unknown source. This unit reaches a maximum thickness of 1,150 feet just east of the Skyline mine.

Age of Mesozoic Rocks

The ages of the Mesozoic rocks in the Oro Blanco district are based entirely on indirect evidence because of the lack of fossils and radiometric dates. Geologic events that are taking place simultaneously over large areas, such as over all of southern Arizona, should contribute meaningful information to the determination of ages. Work by Hayes and Drewes(1968) based upon detailed geological studies and radiometric dates indicates that most of the Cretaceous sedimentary rocks in southern Arizona are Early Cretaceous in age. Furthermore their work indicates a widespread Jurassic igneous episode that is characterized by granite intrusion and rhyolitic volcanism. They also recognize a widespread period of volcanism in Triassic time.

In the Oro Blanco district a thick volcanic section, the Cobre Ridge tuff, is intruded by Warsaw quartz monzonite, both of which have been eroded to form a thick sedimentary sequence. The sedimentary succession is certainly pre-Laramide in age based on structural evidence. Since it overlies a thick volcanic sequence it must be Triassic, Jurassic, or Cretaceous in age because Phanerozoic volcanism older than Triassic is unknown in southern Arizona. The great thickness of the sedimentary rocks combined with the widespread thick sedimentary sections of known Early Cretaceous age in southern Arizona strongly suggests that the Oro Blanco formation is Early Cretaceous in age.

The Oro Blanco formation unconformably overlies the Cobre Ridge tuff and the quartz monzonite which intrudes the tuff, so that these igneous rocks must be no younger than Jurassic. From Hayes and Drewes' work it seems very likely that the quartz monzonite is Jurassic.

The age of the Cobre Ridge tuff is considered here to be Jurassic. The great lithologic dissimilarity between volcanic rocks dated as Triassic in the Santa Rita and Patagonia Mountains a few miles east of the Oro Blanco district seems to rule out a Triassic age for the Cobre Ridge tuff. The Triassic volcanics, although they are in part welded tuffs, are far more alkalic than those at Oro Blanco. They consist largely of albite trachyte and albitic rhyolite (Baker 1961).

Tertiary Rocks

Montana Peak Formation

The name Montana Peak Formation was proposed by Webb and Coryell (1954) for a sequence of dark-colored "rhyolites" unconformably overlying the Mesozoic rocks in the Ruby quadrangle. At the type locality, Montana Peak, they recognize 800 feet of this unit which consists of red and purple breccias, lavas, and tuffs. Study of the Montana Peak Formation in thin section reveals that it consists mostly of andesite and dacite rather than rhyolite. This formation is exposed principally on the west slope of Mule Ridge, but many erosional remnants have been found capping peaks to the west. A small exposure of the lower two members lies just northwest of the Skyline mine in the northwestern part of the district. In addition the Montana Peak Formation covers a large area which has been studied by Nelson(1963) on the southern flank of the Atascosa Mountains.

The Montana Peak Formation comprises a maximum of 1,300 feet of dacite and andesite at the type locality, Montana Peak. The formation is divided into five members based on lithology and texture. These are in ascending order:

1) Andesite member
2) Lower dacite tuff member
3) Lower flow member
4) Upper dacite tuff member
5) Upper flow member

Andesite Member. The andesite member forms the basal part. It is exposed at the foot of Mule Ridge where it unconformably overlies the Mesozoic rocks although locally it has been faulted against Mesozoic rocks. It is conformably overlain by the lower dacite tuff member, and characteristically forms topographic lows which are partly covered by recent gravels.

The andesite member contains rocks having a wide variety of physical characteristics but is mostly of andesitic composition. What seems to be the most abundant type is a greenish-gray crystal-rich andesite porphyry tuff. In hand specimen the rock consists of a light gray aphanitic matrix, phenocrysts of white plagioclase, many irregular greenish clay-altered pumice fragments, and a few fine flakes of biotite. Another fairly abundant variety is a gray strongly flow-banded porphyritic andesite. This rock has a gray aphanitic flow-banded matrix, aligned white phenocrysts of plagioclase 1 to 2 mm in length, and a few aligned hornblende phenocrysts.

In thin section the rock has a microcrystalline groundmass and a fluidal texture composed of aligned andesine phenocrysts and hornblende phenocrysts. Much of the andesine is zoned and has strongly altered cores of zoisite(?). The most calcic zones that are sufficiently unaltered to determine their composition yield a value of An_{46}. The hornblende has been partly replaced by chlorite. Very sparse quartz crystals are present as well. The estimated composition of this rock is:

Quartz phenocrysts	<1%
Andesine phenocrysts	20
Hornblende and chlorite	5
Groundmass	73
Zoisite	2

Other varieties of minor abundance include dark green porphyritic andesite and dark purple biotite andesite porphyry flows.

Much of the andesite member has a moderate to steeply dipping foliation that seems to have little or no relation to the attitude of the gently dipping contacts. Using the attitudes of the contacts rather than the foliation, one arrives at a maximum thickness of about 150 feet for the andesite member.

Lower Dacite Tuff Member. The lower dacite tuff member generally overlies the andesite member although in many places it rests unconformably on Mesozoic rocks. It is conformably overlain by the lower flow member. This unit is more resistant to erosion than the underlying andesite and forms rounded hills of moderate relief. The rock weathers white so that the outcrops stand out boldly against the darker colored rocks in the adjacent members. The unit consists mainly of dacite tuff which reaches a maximum thickness of 450 feet.

In hand specimen the rock has a light greenish-gray aphanitic matrix and a great number of angular white and light tan aphanitic lithic fragments. Phenocrysts are very sparse but consist of white plagioclase and a few small quartz grains. Some of the rock is a tuff but much of it is better classified as a tuff-breccia for the lithic fragments are commonly several inches in length.

In thin section the rock has a siliceous microcrystalline matrix and a fragmental texture. A few broken phenocrysts of quartz and andesine(An_{42}) are distributed throughout, along with many angular lithic fragments consisting of microcrystalline volcanic material. Carbonate and epidote are minor alteration products. The estimated composition of this rock, which seems to be a dacite or rhyodacite, is:

Quartz fragments	3%
Andesine fragments	1
Lithic fragments	20
Matrix	75
Accessory minerals	1

As in the andesite member the foliation is at variance with the nearly horizontal attitudes of the contacts. Foliation in this member is rather sparse, but that which has been measured ranges in dip from 15° to 80°.

Lower Flow Member. The lower flow member conformably overlies the lower dacite tuff member although in the northeast it unconformably overlies the Oro Blanco formation. This member is conformably overlain by the upper dacite tuff and disconformably overlain by the Atascosa Formation. This member consists of a maximum of 750 feet of andesite porphyry flows, dacite flows, and minor pyroclastics. The andesite generally forms slopes, whereas the dacite is a cliff former.

Approximately the lower two-thirds of the lower flow member is composed of andesite which occurs as two principal types. The more abundant type is a pinkish-gray porphyritic biotite andesite which has phenocrysts of white plagioclase 3 to 4 mm in length, a few black biotite flakes, and hornblende needles which have been aligned by flowage. A few specimens of this rock contain very sparse quartz phenocrysts as well. In thin section the andesite has a microcrystalline fluidal groundmass of plagioclase microlites, phenocrysts of andesine (An_{38}), hornblende, and minor quartz. Hornblende is generally replaced by chlorite. Generally the rock occurs as flows, but small areas of volcanic breccia composed of andesite that resemble this type have been observed in the field.

A less abundant rock in the lower flow member is a dark red-purple aphanitic flow-banded andesite. No thin sections of this rock have been examined, but judging from the dark coloration and a few sparse plagioclase phenocrysts it probably is an andesite. This type is most abundant just west of Chiminea Peak where the author has mapped the attitudes of flow banding in a part of an individual flow unit (Figure 3).

The upper one-third of the lower flow member is exposed on the west slope of Mule Ridge. The rock here is a pink, flow-banded porphyritic dacite. In hand specimen it has a pink, aphanitic, flow-banded matrix, many aligned clear plagioclase phenocrysts, and a few hornblende phenocrysts. Some specimens contain spherulites as well.

Under the microscope the rock has a microcrystalline groundmass in part composed of tridymite and fine-grained hematite. Zoned plagioclase phenocrysts and quartz phenocrysts generally have a seive texture in which numerous perforations in the phenocrysts are filled with microcrystalline matrix. Hornblende has been partly replaced by hematite. The estimated composition of this rock is:

Quartz phenocrysts	6%
Plagioclase phenocrysts	22
Hornblende (Hematite in part)	5
Matrix	67

Upper Dacite Tuff Member. The upper dacite tuff conformably overlies the lower flow member. The rock is very similar in composition and general appearance to the lower dacite tuff member but is somewhat thinner, 350 feet in maximum thickness. In contrast to the lower dacite tuff the foliation attitudes in the upper tuff do conform to the gently dipping contacts. The unit lacks any obvious sorting of the lithic fragments and foliation is very faint suggesting that it may be an ash flow tuff.

In hand specimen the rock consists of angular lithic fragments, principally fine-grained sandstone, and flow-banded aphanitic dacite(?) in a pink aphanitic matrix. Clear plagioclase phenocrysts are sparsely distributed through the matrix along with a small amount of black biotite. In thin section the matrix consists of partly devitrified glass in which outlines of unflattened shards are visible. Plagioclase phenocrysts are zoned and have seive structure similar to those in the lower flow member. The estimated composition is:

Quartz phenocrysts	<1%
Plagioclase phenocrysts	11
Biotite	5
Lithic fragments	10
Matrix	64

Upper Flow Member. The upper flow member is very similar to the upper part of the lower flow member. It consists of a maximum of 270 feet of pink porphyritic flow banded dacite that in hand specimen is identical with the dacite of the lower flow member. This unit forms the cliffs at the top of Montana Peak and caps much of Mule Ridge (Figure 6).

In thin section this rock is likewise similar to that in the lower flow member but the matrix is more glassy and quartz phenocrysts are far less abundant. The plagioclase, however, has the characteristic seive texture and has been aligned by flowage. Hornblende has likewise been aligned by flowage. In addition a small amount of biotite is present.

The attitudes of the foliation in this unit in general conform to the gently dipping contacts. The attitudes shown on Figure 3 are taken on the contacts of individual flow units rather than foliation.

Figure 6. Mule Ridge, Showing Members of Montana Peak Formation

Tmp$_1$	Andesite member
Tmp$_2$	Lower dacite tuff member
Tmp$_3$	Lower flow member
Tmp$_4$	Upper dacite tuff member
Tmp$_5$	Upper flow member
Mes.	Mesozoic rocks

The upper flow member conformably overlies the upper dacite tuff member and is disconformably overlain by the Atascosa Formation.

Atascosa Formation

The Tertiary Atascosa Formation was named by Webb and Coryell (1954) for a sequence of rhyolite flows and tuffs that aggregate 800 feet in thickness in the Atascosa Mountains, the type locality. This unit is exposed principally on the eastern flank of Mule Ridge although one small erosional remnant has been found near the summit of Bartlett Mountain 2 miles west of Mule Ridge. The Atascosa Formation characteristically is a cliff-former. It forms nearly vertical white escarpments at Ruby Peak and Chiminea Peak; and similar, though much higher escarpments in the Atascosa Mountains several miles east of the Oro Blanco district.

In the Oro Blanco district two distinctly different types of rock comprise the Atascosa Formation. The more abundant is a strongly flow banded rhyolite which forms the upper and lower parts of the formation. Less abundant is a rhyolitic ash flow tuff that lies in the central part. This tuff has been mapped separately and termed the tuff member. The formation reaches a maximum thickness of 1,800 feet within the area of study of which a maximum of 250 feet is composed of the tuff member.

Rhyolite flows comprise most of the Atascosa Formation. These consist of strongly flow banded spherulitic rhyolite that varies from light gray to yellow to brownish red. Flow banding is commonly very chaotic reflective of the high viscosity of the rhyolite lavas. The rock weathers to very rugged topographic forms which have extremely rough surfaces.

In hand specimen the rock is a strongly banded felsite that is rich in spherulites and opaline streaks. These are commonly very brilliantly colored in shades of red, orange, green, and blue. Agate nodules are common in parts of this unit. Phenocrysts are difficult to find and usually are very small. These generally are quartz or pink potash feldspar.

In thin section the rock is seen to consist of a partly devitrified glassy matrix that is strongly flow banded, and exceedingly sparse phenocrysts of quartz and sanidine. The phenocrysts total less than one percent of the rock. In some specimens, spherulites filled with chalcedony are very abundant, making up an estimated 30 percent of the rock.

The rhyolite flows overlie the Montana Peak Formation disconformably and are unconformably overlain by Tertiary gravels. The rhyolites are relatively flat lying, dipping only a few degrees, generally to the northeast.

Tuff Member. The tuff member lies in the central portion of the Atascosa Formation and is conformable to the overlying and underlying rhyolite flows. This member is exposed on Mule Ridge and on Bartlett Mountain. In addition it occupies many square miles in the Atascosa, Tumacacori, and Cerro Colorado Mountains. In the Oro Blanco district the tuff member has a basal vitrophyre which ranges from a few inches to about 10 feet in thickness. This is composed of a dark greenish-gray glass having a few phenocrysts of potash feldspar and quartz.

Overlying the vitrophyre is a sequence of crudely stratified to unstratified tuffs. These are light gray to light greenish-yellow tuffs that locally are very rich in dark colored lithic fragments (Figure 7). The lithic fragments range from a fraction of an inch to several inches in length. These consist of flow-banded rhyolite, flow banded dacite, arkose, sandstone, and dark-red andesite. The matrix of the tuff is very porous and seems to be mostly pumice. Phenocrysts are sparse.

In thin section the rock has a definite vitroclastic texture. The groundmass is a myriad of partially flattened shards that generally have crystallized to cristobalite. Phenocrysts are sparse but consist of quartz, sanidine, and strongly sericitized plagioclase.

The large areal extent and the texture of this member indicate that it is an ash flow tuff. Foliation dips very gently to the east or northeast conformable to the underlying rhyolite flows. This combined with the ash flow origin makes an ideal marker unit for regional correlation. The light-toned tuff member is easily recognized and followed on aerial photographs, and is traceable in the field with a minimum of effort. Mapping of the tuff member shows that it correlates with the Corral de Piedras welded tuff exposed at Tumacacori Peak in the Tumacacori Mountains. The basal vitrophyre of the Corral de

Figure 7. Tuff Member of the Atascosa Formation

This exposure consists mostly of white pumice and many fragments of red and purple dacite from the Montana Peak Formation.

Piedras welded tuff has been dated at 26.5 ± 1.2 million years (Damon and Bikerman 1964). Thus the tuff member is of late Oligocene age.

At Bartlett Mountain the tuff member has been intruded by Tertiary rhyolite dikes that probably served as feeders for much of the Atascosa Formation.

Tertiary Gravels and Tuffs

At the eastern edge of the area of study the Tertiary volcanic rocks are overlain by a sequence of poorly consolidated gravels and interbedded tuffs. These are unconformable on the underlying volcanic rocks. The total thickness of this unit is not known but probably is only a few hundred feet at most.

The Tertiary gravels and tuffs consist of poorly sorted sandy gravels and interbedded white tuffs derived from the underlying Tertiary rocks. The tuffs are generally very rich in lithic fragments and have a matrix of white clay; probably altered volcanic ash. Individual beds in this unit are thin, ranging from a few inches to about 2 feet in thickness.

The slight degree of consolidation of the gravels and their minor angular discordance to the underlying volcanic rocks suggests that the beds are Late Tertiary in age, probably Miocene or Pliocene.

Quaternary Rocks

Gravels

Unconsolidated alluvial deposits cover parts of the lowlands in the Oro Blanco mining district along stream courses. In addition a pediment area, an embayment of which lies just west of the study area, is covered with a mantle of the sediments.

Regional Correlation

In order to better establish the geologic ages of the various rock units exposed in the Oro Blanco district an attempt was made at regional correlation with the hope of tracing one or more units far enough to tie into areas where radiometric dating has been completed. Although the writer has been able to correlate with some certainty units in the Oro Blanco Mountains with those in several other mountain ranges, in no case have any of the Mesozoic volcanic units equivalent to those at Oro Blanco, been dated radiometrically.

Correlation of Mesozoic rocks in southern Arizona is rather difficult for several reasons. Except for the southeastern part of the state most of the Mesozoic sedimentary rocks are of terrestrial origin and very local in their lateral extent. They rarely contain good guide fossils, in fact, fossils of any kind are relatively uncommon. Another problem with regional correlation is due to volcanism, which was widespread in Mesozoic time in southern Arizona. Commonly volcanic rocks are very restricted in their lateral extent, although near their source they may be very thick, sometimes several thousand feet. In addition to thickening the section in a given area the presence of the volcanic pile causes changes in sedimentation so that the stratigraphic section in one range might be entirely different from another range only a few miles away even though the deposits are synchronous.

One way to circumvent the difficulties of regional correlation is to find a unit or units which is characterized by widespread lateral uniformity and uniqueness in some property such as texture or composition. Units which meet these requirements are the ash flow tuff sheets common in the Mesozoic and Cenozoic record of southern Arizona.

For regional correlation the ash flow sequences of the Cobre Ridge tuff and tuff member of the Atascosa formation prove to be of great value. In addition the thick sedimentary sequence overlying the Cobre Ridge tuff seems likewise to correlate well on a regional scale. Lithologic and textural similarity, thickness, and structural setting including direction and amount of dip and relationship to major faulting have been considered in making the correlations. The relationships to be discussed below are summarized on the correlation chart, Figure 8.

Las Guijas Mountains

The correlation of the Mesozoic rocks in the Guijas Mountains with those at Oro Blanco is a relatively simple matter for it involves little more than tracing the units along strike between the two areas. The Oro Blanco formation, Cobre Ridge tuff, and an intrusive body having geologic relations and appearance similar to the Warsaw quartz monzonite have been recognized in the Guijas range.

The Cobre Ridge tuff here is very similar to that at Oro Blanco. It consists of an upper, dark-colored welded part that is compositionally a quartz latite. In McCafferty Canyon this upper part is about 4800 feet in thickness unless there has been some undetected repetition by faulting. Underlying this is at least 4,700 feet of rhyolite porphyry tuffs, that in hand specimen and thin section are very similar to the rhyolite tuffs comprising the rhyolite member of the Cobre Ridge tuff at Oro Blanco. The base of the Cobre Ridge tuff in the Guijas range is in fault contact with Oro Blanco formation.

The Oro Blanco formation here differs little from that exposed in the area of study except that there seems to be a greater abundance of shale and siltstone here, whereas at Oro Blanco sandstones and pebbly sandstones are more common. In addition the coloration is somewhat different in the Guijas Mountains, the fine-grained sediments tend to be mostly maroon whereas at Oro Blanco there is a greater abundance of green, purple, and brown beds. Here, as at Oro Blanco, the thickness of the Oro Blanco conglomerate member ranges widely from zero to several hundred feet.

A stock of equigranular leuco-quartz monzonite intrudes the Cobre Ridge tuff at the northwest end of the Guijas range. The appearance in hand specimen and its lack of intrusion into the overlying Oro Blanco formation suggests that the body may be genetically related to the Warsaw quartz monzonite.

Pajarito Mountains

The Pajarito Mountains (Figure 9) lie a few miles southeast of Ruby. The eastern end of the Pajarito Mountains has been studied by Nelson(1963), who recognizes many of the same units that occur in the Oro Blanco district. The older Mesozoic unit, the Pajarito lavas, seems to be merely a continuation along strike of the Cobre Ridge tuff. This unit is identical in hand specimen and in thin section to the Cobre

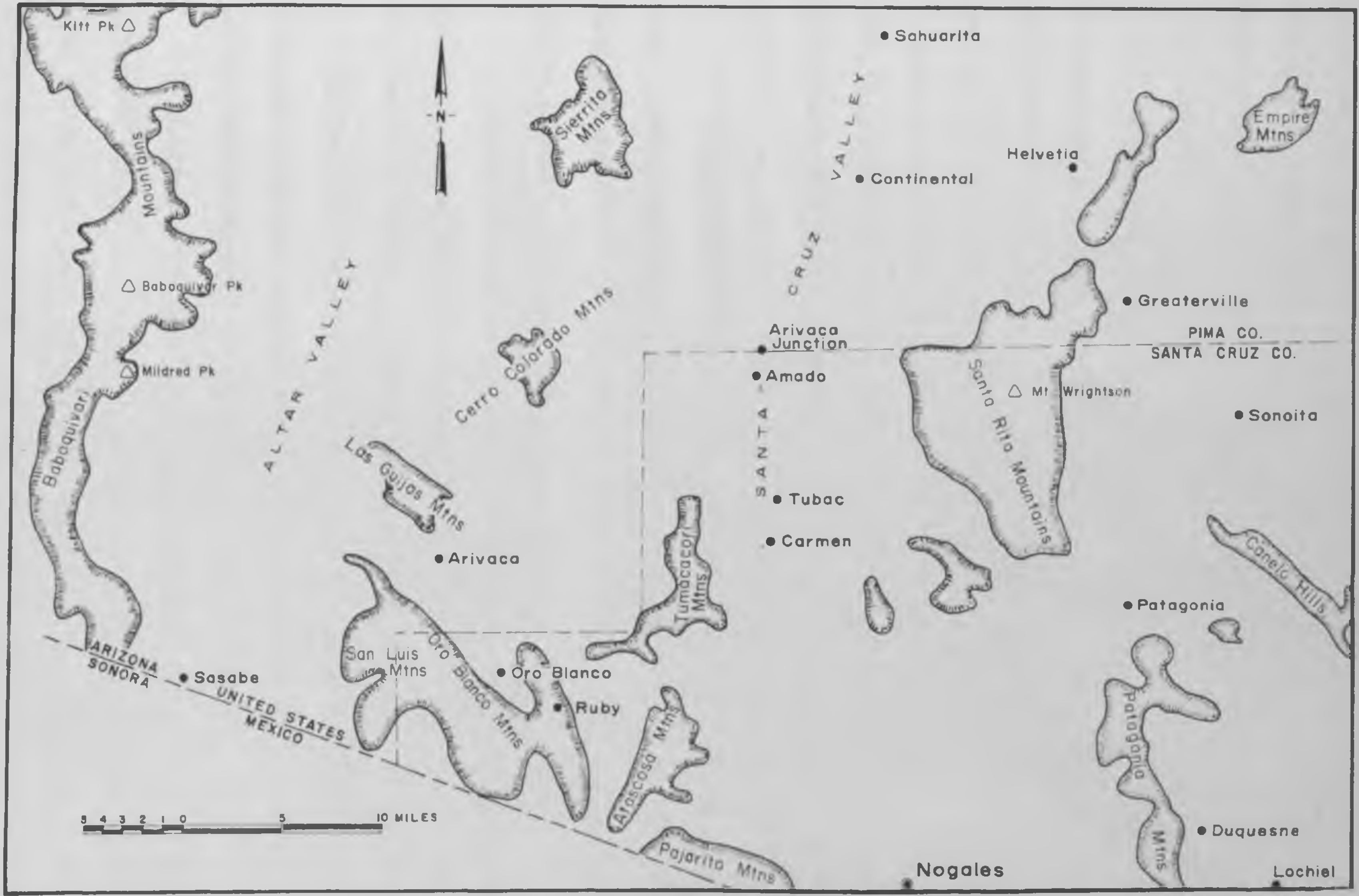


Figure 9. Mountain Ranges of Southern Arizona

Ridge tuff. The Pajarito lavas seem to be dominantly tuffaceous, so the name is somewhat misleading. Nelson recognizes a minimum of 1,300 feet of this unit in his study area. The bottom of the unit has not been observed.

Unconformably overlying the Pajarito lavas is the Oro Blanco conglomerate of which a 200 foot thickness appears in Nelson's area. Reconnaissance mapping by the present author shows that in the central part of the Pajarito Mountains the conglomerate is much thicker possibly as much as 4,000 feet, but faulting may have thickened the section so that this figure is very uncertain. The reconnaissance mapping also disclosed a thin black limestone unit and several hundred feet of sandstone and siltstone which conformably overlie the conglomerate.

In the eastern Pajarito Mountains the Oro Blanco formation is unconformably overlain by the Montana Peak Formation. Here the Montana Peak Formation is much thinner than at Montana Peak in the Oro Blanco district, reaching a maximum thickness of 600 feet.

Nelson(1963) finds that the Montana Peak formation is overlain unconformably by the Atascosa Formation, a relationship that is not apparent at Oro Blanco. Compositionally the Atascosa Formation is somewhat different in the Pajarito Mountains. The unit consists mostly of rhyolitic tuffaceous beds rather than flows. Nelson finds a maximum of 400 feet of Atascosa Formation in his study area.

Overlying the Atascosa Formation is about 350 feet of poorly indurated interbedded gravels and white tuffs that Nelson calls the Peña Blanca formation. He considers this to be Quaternary in age on the basis of slight angular discordance and structural differences between this unit and the underlying Tertiary rocks. The Peña Blanca formation is very similar to the Tertiary gravels and tuffs exposed at the eastern edge of the present study area.

Baboquivari Mountains

The Baboquivari Mountains (Figure 9) lie about 10 miles to the west and northwest of the Guijas Mountains and about 12 miles west of the Sierrita Mountains. The geology of only a small part of this range is known in detail. The central part of the range near Fresnal Canyon has been studied by Donald(1958), Fair(1965), and Heindl and Fair(1965). Figure 10 is a geologic map of the area studied by Heindl and Fair.

Heindl and Fair divided the stratified Mesozoic rocks into four formations from oldest to youngest, Ali Molina Formation, Pitoikam Formation, Mulberry Wash Volcanic Formation, and the Chiuli Shaik Formation. These units as defined make a Mesozoic section that is nearly 20,000 feet thick. The Ali Molina Formation consists mainly of slightly metamorphosed quartz latite porphyry with minor interbedded clastic sedimentary rocks. The upper part of this unit is a coarse phyllitic conglomerate. The Pitoikam Formation consists of about 9,200 feet of sedimentary rocks of which the lower half is a coarse conglomerate composed mainly of fragments of quartz latite from the Ali Molina Formation. The upper part of this unit consists of maroon and green sandstones, mudstones, and shales.

Overlying the Pitoikam Formation is the Mulberry Wash Volcanic Formation. The lower 1,100 feet of this unit is a quartz latite porphyry locally having strong "flow" banding. Overlying this is about 900 feet of conglomerate that is composed of rounded quartz latite cobbles and boulders. Heindl and Fair(1965) state, p. 110, "--the unit is similar to the Contreras Conglomerate member of the Pitoikam Formation". The upper 1,000 feet of this formation consists mostly of latite porphyry and andesite porphyry with some fine-grained clastic sedimentary beds.

The uppermost Mesozoic formation is the Chiuli Shaik which consists of a lower sedimentary unit and an upper volcanic unit. The lower unit is made up of 750 feet of red and brown conglomerate, mudflows, and gray-green graywacke beds. The upper unit consists of purple andesite and overlying rhyolite comprising a thickness about 1,000 feet.

Although Heindl and Fair do not mention it, the possibility exists that Mulberry Wash Volcanic Formation is a faulted repetition of the Pitoikam and Ali Molina Formations. The presence of quartz latite porphyry and conglomerate of similar description in the Ali Molina and Mulberry Wash sections, suggests that such repetition may have occurred. Heindl and Fair(1965) state regarding the contact between the Mulberry Wash and Pitoikam Formations, p. 110, "In general, the disconformity between the two formations is masked by gouge along shearing planes and by deposition of black manganese minerals in the zone of shearing." From this statement one may infer that the contact

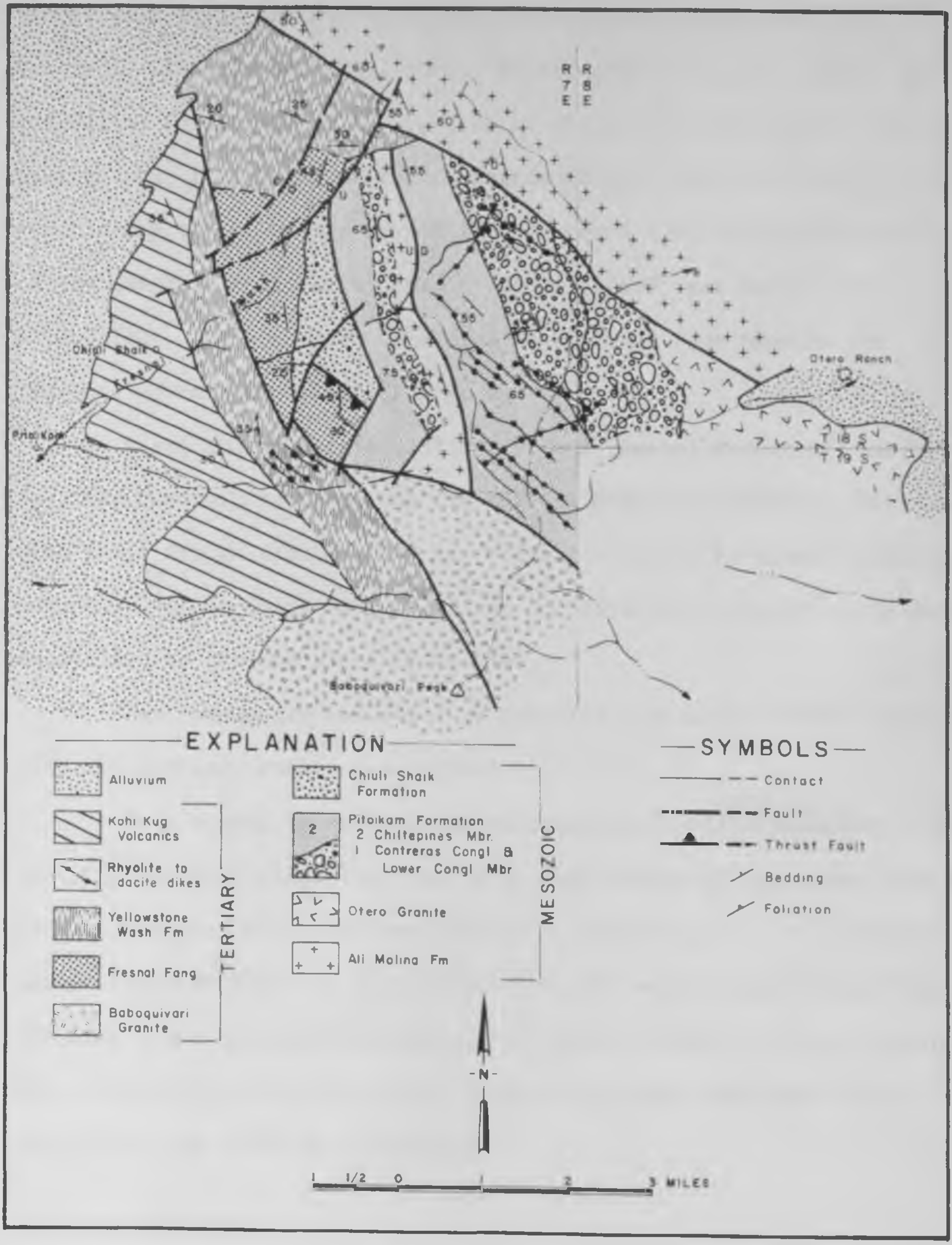


Figure 10 Geologic Map of the Fresnal Canyon Area, Baboquivari Mountains (modified after Fair 1965 and Heindl and Fair 1965)

itself is a major northwest-striking fault that has repeated the section. Likewise the conglomerate reported in the upper part of the Ali Molina Formation may be the same as the conglomerate in the basal part of the Pitoikam Formation as suggested by Heindl and Fair, p. 16. If this repetition of the section has occurred then the total thickness of the Mesozoic rocks here would be about 17,000 feet rather than 20,000 feet. This revised thickness is what has been used in the regional correlation chart (Figure 8).

Based on lithologic similarity, and general structural similarity, the Mesozoic rocks of the Baboquivari Mountains probably correlate with those at Oro Blanco. The Ali Molina Formation is likely to be the same unit as the Cobre Ridge Tuff and the Pitoikam Formation is probably equivalent to the Oro Blanco Formation.

Tertiary units described by Fair(1965) probably do not correlate with the Tertiary rocks at Oro Blanco.

Fair mapped several northwest-trending rhyolite to dacite dikes that cut Tertiary units that may be a continuation of the swarm in the southern part of the Oro Blanco district. What seems to be the same swarm mapped by Fair has been observed by the author near Mildred Peak. Here the swarm consists of numerous northwest-striking steeply dipping, pink rhyolite porphyry dikes that form steep-sided resistant ridges similar to the dikes at Oro Blanco.

Sierrita Mountains

Thoms(1965) reports on the geology of the western side of the Sierrita Mountains (Figure 9). He describes two formations, the Ox

Frame volcanics and the Tascuela red beds, that probably correlate with the Cobre Ridge tuff and Oro Blanco formation.

The older unit, the Ox Frame volcanics consists of four members; an upper rhyolite member composed of welded tuffs and thin flows; andesite porphyry member composed of flows and interfingered with the coarse tuff member; and a lower tuff-breccia member composed of rhyodacitic tuff and flow breccias. The formation is at least 5,100 feet thick.

In a brief visit to Thom's study area it was discovered that the coarse tuff member strongly resembles many of the weakly welded parts of the Cobre Ridge tuff near the base of the welded tuff member. Descriptions given by Thoms for this member are very similar to the characteristics observed for the Cobre Ridge tuff.

Hayes and Drewes(1968) report that radiometric dates on the Ox Frame volcanics of Ox Frame Canyon indicate them to be of Triassic age. They further report that these rocks are very similar to banded rhyodacite and andesite of the Triassic Mount Wrightson Formation in the nearby Santa Rita Mountains. Observations by the author on the Ox Frame volcanics at the type locality in Ox Frame Canyon, Sierrita Mountains suggest that the rocks referred to as Ox Frame volcanics by Thoms(1965) may not correlate with the true Ox Frame volcanics. Thoms expressed some doubt about correlating his "Ox Frame volcanics" with those in Ox Frame Canyon principally because the Ox Frame type section had not been adequately described at the time of his work. If these two sections do not correlate, then it is possible that the volcanic rocks described by Thoms are younger, possibly Jurassic in age.

Overlying the Ox Frame volcanics (of Thoms) are the Tascuela red beds which consist of about 200 feet of basal conglomerate and 1,800 feet of maroon shales argillites and sandstone that Thoms considers to be of Cretaceous(?) age. The thick basal conglomerate suggests that a substantial period of erosion occurred after emplacement of the underlying volcanic rocks which might be comparable to the erosion period that occurred after emplacement of the Cobre Ridge tuff at Oro Blanco. The sedimentary beds comprising the Tascuela red beds do resemble much of the Oro Blanco formation, so that these units may be correlative. In addition, an intrusive rock reportedly having a Jurassic age (Hayes and Drewes 1968) and considered to be Nevadian in age by Thoms has been found as boulders in the basal conglomerate of the Tascuela red beds (Thoms 1965, p. 45). Therefore the Tascuela red beds unconformably overlie Jurassic rocks and may be no older than Cretaceous. These beds have been badly faulted, tilted steeply and are unconformably overlain by Tertiary rocks so that they are most likely Cretaceous in age. In addition the work of Hayes and Drewes(1968) seems to indicate that in southern Arizona the deposition of thick Cretaceous sedimentary sequences was limited to the earlier part of Cretaceous time.

Conformably overlying the Tascuela red beds, Thoms describes a unit termed the Stevens Mountain rhyolite consisting of volcanic conglomerate and rhyolite welded tuffs that comprise a thickness of 2,000 feet. No unit has been found in the Oro Blanco Mountains that seems to correlate with this unit.

Unconformably overlying the Stevens Mountain rhyolite is the Demetric Formation of probable Cretaceous-Tertiary age. This unit consists of dacite and andesite tuff-breccia and minor conglomerate. The Demetric Formation has a maximum thickness of about 2,000 feet.

The Demetric Formation is lithologically similar to the andesite that blankets much of the Cerro Colorado mining district, but it is uncertain if it correlates with the andesites and dacites of the Montana Peak Formation at Oro Blanco. In the Sierritas the Demetrie Formation is overlain with angular unconformity by Tertiary rocks, whereas the Montana Peak Formation seems to be overlain disconformably by Tertiary rocks. This does not rule out these units from being correlative for it is possible that an angular unconformity exists between the Montana Peak formation and the overlying rocks that is not apparent in the Oro Blanco district. Work by Nelson(1963) suggests there is an angular unconformity between these units (see Pajarito Mountains under Regional Correlation).

Patagonia Mountains

The Patagonia Mountains (Figure 9) lie about 30 miles east of the Oro Blanco mining district and about 18 miles east of the Pajarito Mountains. Baker(1961) studied the geology of the southeastern

Patagonia Mountains and reports an exceedingly thick Mesozoic stratigraphic section that may in part correlate with Mesozoic rocks at Oro Blanco.

Baker describes a thick sequence of volcanic rocks, the Duquesne volcanics, 8,000 feet in thickness, that probably correlate with the Triassic Mount Wrightson series of the Santa Rita Mountains (Hayes and Drewes 1968). At the time of his study in the Patagonias, Baker considered these rocks as simply pre-Cretaceous, however he now considers them to be Triassic (Baker, personal communication). Much of the Duquesne volcanics consists of albitized trachyte, rhyolite, and andesite; but the upper 1,200 feet of this unit is a quartz latite crystal-vitric tuff, part of which is a welded tuff. This unit unconformably overlies the rest of the Duquesne volcanic sequence. Although the present author has not examined this rock in the field, Baker's description of it shows that it is similar to the Cobre Ridge tuff, and may be correlative with the Cobre Ridge tuff.

Unconformably overlying the Duquesne volcanics is the Bagby Ranch formation which consists of an estimated 2,800 feet of coarse to fine grained clastic sedimentary rocks. The Bagby Ranch formation has a basal conglomerate which is overlain by sandstone and interbedded shale, siltstone, and conglomerate.

A disconformity marked by a few feet of conglomerate separates the Bagby Ranch formation from the overlying Lower Cretaceous Molly Gibson Formation. The Molly Gibson has been dated paleontologically as Albian (Uppermost Lower Cretaceous). The Molly Gibson

Formation has an estimated thickness of 4,000 to 4,500 feet and consists of red and purple sandstone, purple sandy shales, and minor limestone, interbedded with abundant shale.

The unconformity at the base of the quartz latites in the Triassic Duquesne volcanics leaves open the possibility of a Jurassic age for the quartz latite. The present author correlates this unit, which may be Jurassic in age, with the Cobre Ridge tuff.

The Bagby Ranch formation is at a similar position in the stratigraphic column and is similar in composition to the Oro Blanco formation so that these two units have been correlated. The Bagby Ranch formation is probably Early Cretaceous in age. The disconformity between this unit and the overlying Lower Cretaceous Molly Gibson Formation probably represents only a minor time break compared to the major unconformity at the base of the Bagby Ranch formation. For this reason the unconformity at the base of the Bagby Ranch formation, instead of the disconformity at the base of the Molly Gibson Formation, is here considered to be the Jurassic-Cretaceous unconformity.

Unconformably overlying the Molly Gibson Formation is about 500 feet of conglomerate that in turn is unconformably overlain by a thick sequence of volcanic breccia and conglomerate composed of Mesozoic rock fragments in a tuffaceous matrix. This unit is conformably overlain by about 2,000 feet of porphyritic andesite flows. Baker considers the volcanic breccia and the andesite to be Early Tertiary in age. These rocks may be equivalent to the Montana Peak Formation. Unconformably overlying the andesite is a sequence of rhyolite flows considered by Baker to be Mid-Tertiary in age. Unconformably overlying the rhyolite flows is an unknown thickness of poorly consolidated bedded tuffs and breccias. These two units might be equivalent to the Atascosa Formation and the Tertiary gravels and tuffs, respectively.

Cerro Colorado Mountains

Most of the exposed parts of the Cerro Colorado Mountains (Figure 9) have been mapped by Davis(1955), Jones(1957), and Smith (1966). The units here of probable Mesozoic age are very much like those in the Oro Blanco district. The oldest Mesozoic unit is a thick sequence of quartz latite tuffs and flows that in hand specimen and thin section strongly resembles the Cobre Ridge tuff. Arkosic sandstone is interbedded with the volcanic rocks near the top of the section. The author has observed a minimum thickness of 2,000 feet for the quartz latite but it is likely to be much thicker than this. The geologic maps that accompany Davis' and Jones' works do not show any foliation attitudes in this unit so that a thickness estimate is not possible at this time.

Overlying the quartz latite is a coarse-grained conglomerate made up of pebbles, cobbles, and boulders of the underlying volcanic rocks. This looks much like Oro Blanco conglomerate. The conglomerate is overlain by minor limestone and fine-grained clastic rocks which probably are several thousand feet in thickness. The conglomerate and the overlying fine-grained clastic rocks probably correlate with the Oro Blanco formation.

A sequence of porphyritic andesite breccias and flows unconformably overlies the sedimentary rocks and the quartz latites. The andesites have been structurally disturbed by faulting but less so than the underlying rocks. These rocks resemble somewhat the Demetric Formation of the Sierrita Mountains a few miles to the north. They are overlain by Tertiary rhyolite that probably is equivalent to the Atascosa Formation. It is uncertain, but the andesites at Cerro Colorado probably correlate with those of the Montana Peak formation at Oro Blanco.

Summary

Although some of the Mesozoic and Tertiary stratigraphic units are correlated on a regional scale with a great deal of uncertainty, at least two of these units, the equivalents of the Cobre Ridge tuff and the Oro Blanco formation seem to be recognizable over a very large part of southern Arizona. Regional correlation is a definite aid in establishing the ages of the rocks at Oro Blanco where the lack of paleontological and radiometric dates makes absolute age determination difficult. The relationships observed during the regional correlation work support the inferred ages of Jurassic for the Cobre Ridge tuff and Early Cretaceous for the Oro Blanco formation.

INTRUSIVE IGNEOUS ROCKS

The intrusive igneous rocks of the Oro Blanco mining district include rocks of Jurassic(?) through Tertiary age. The Jurassic(?) and Cretaceous(?) rocks occur as stock-like and sill-like masses respectively, whereas the Tertiary rocks occur only as dikes and plugs.

Jurassic(?) Rocks

Warsaw Quartz Monzonite

The name Warsaw quartz monzonite is a new one proposed for equigranular quartz monzonite of Jurassic(?) age exposed in the central and extreme southwestern parts of the Oro Blanco mining district. The unit has not been previously recognized although a brief discussion by Fowler(1938) of quartz monzonite encountered in a drill hole beneath the Montana mine may refer to this rock. The quartz monzonite is named for the Warsaw Canyon road which passes near several exposures of the rock.

The Warsaw quartz monzonite has two principal compositional varieties within the Oro Blanco district, a leuco-quartz monzonite and a mafic-rich quartz monzonite or granodiorite. The leuco-quartz monzonite is exposed in the central part of the district just west of the Warsaw Canyon road and in the extreme southwest along the International Boundary. The mafic-rich variety occupies a large area west of Bartlett Mountain and a small part of the northern edge of the southwestern leuco-quartz monzonite mass.

Leuco-quartz monzonite. In hand specimen the leuco-quartz monzonite is a yellowish tan equigranular coarse to fine grained quartz monzonite. Gray quartz, white slightly altered plagioclase, and pinkish-gray potash feldspar are the principal minerals although very sparse flakes of muscovite have been seen in a few exposures. The grain size ranges from about 1 mm near the contacts to about 5 mm in the central parts of the bodies.

In thin section the rock has a granitic texture consisting of subhedral to euhedral altered plagioclase, and subhedral to anhedral quartz and perthitic microcline. The quartz generally shows undulatory extinction. The plagioclase composition is uncertain because of strong clay alteration. Composition based on point counting in one thin section is:

Quartz	26%
Perthitic microcline	53
Plagioclase (mostly clays)	20
Accessory minerals	1

Mafic-rich quartz monzonite. In hand specimen the mafic-rich variety of the Warsaw quartz monzonite is seen to be an equigranular rock which is composed of greenish-gray altered plagioclase, grayish-pink potash feldspar, and liberal amounts of chlorite or biotite and hornblende. Quartz is difficult to distinguish as it is generally rather fine-grained and interstitial to the other minerals. The grain size ranges from about 2 mm to nearly 1 cm.

Under the microscope the rock has a granitic texture or in some cases intersertal texture. The rock consists of euhedral to subhedral zoned plagioclase, anhedral orthoclase, anhedral quartz and euhedral grains of hornblende and biotite. The zoned plagioclase ranges in composition from about An_{20} to An_{38}, the more calcic zones forming the cores of the crystals. Most samples observed in thin section contain both hornblende and biotite although the relative proportions differ from section to section. The mafic minerals usually are partly replaced by chlorite and the plagioclase is partly sericitized. The orthoclase is generally unaltered.

This variety of Warsaw quartz monzonite is classed as a quartz monzonite or a granodiorite. Compositions based on point counting of two thin sections are as follows:

Quartz	17%	25%
Orthoclase	21	26
Plagioclase	45	38
Hornblende	8	1
Biotite	8	10
Accessory minerals	1	<1

The Warsaw quartz monzonite is the oldest intrusive rock in the Oro Blanco district. It is the only plutonic rock which has contributed cobbles and boulders to the Oro Blanco Conglomerate. These fragments are especially abundant in the conglomerate one half mile south of the Montana mine. The quartz monzonite has intruded only the Cobre Ridge tuff, but has cut all three members of this formation.

The sharpness of the contacts between the Warsaw quartz monzonite and the volcanics varies with the member involved. Where the quartz monzonite intrudes the rhyolite member the contacts are gradational over a distance of several feet. Considerable mixing of the two rocks takes place at the contacts that probably is the result of partial assimilation of the rhyolite tuff by the intrusive. Contacts between the arkose member and the quartz monzonite exhibit a similar gradation. Although the contacts between the quartz monzonite and welded tuff member are poorly exposed,at the few places that have been observed they are relatively sharp. The quartz monzonite usually has a chill zone several tens of feet in width adjacent to contacts with the welded tuff member.

The relative ages of the two varieties of the quartz monzonite are unknown. The few contacts that have been observed between these types are gradational over several feet. As one passes from the mafic-rich to the leuco-quartz monzonite the only major change is a gradual reduction in the percentage of mafic constituents. Inclusions of one variety in the other have not been found. If the two varieties are genetically related then it is likely the more basic mafic-rich rock is the older.

Cretaceous(?) Rocks

Ruby Diorite

The Ruby diorite of Cretaceous(?) age, named by Fowler(1938), is a dark gray hornblende diorite that forms the footwall of the Montana vein at Ruby. The diorite lies in a nearly north-south trending belt in the central part of the Oro Blanco district.

In hand specimen the Ruby diorite is a dark greenish gray porphyritic rock composed of white plagioclase phenocrysts 2 to 5 mm in length and hornblende needles distributed through a fine-grained matrix of feldspar and hornblende. The rock weathers to a light bluish gray or a yellowish tan. Commonly the hornblende phenocrysts are aligned parallel to one another.

Under the microscope the rock has a finely crystalline groundmass of plagioclase, potash feldspar, and quartz. Phenocrysts of zoned plagioclase and hornblende are very abundant whereas only a few phenocrysts of quartz have been observed. The hornblende has a strong preferred orientation. The rock is generally slightly altered, the hornblende partly or totally replaced by chlorite or epidote, and the plagioclase sericitized. The rock is actually a granodiorite or quartz diorite, but because of the appearance in hand specimen no formal change of name is proposed for this unit. The modal composition from point counting one thin section is:

Quartz phenocrysts	2%
Plagioclase phenocrysts	23
Hornblende phenocrysts	13

Matrix (quartz and K-spar rich)	59
Miscellaneous	3

Ruby diorite occurs principally as a thick sill within the Oro Blanco formation. It has been extensively faulted to produce the numerous exposures in the central part of the district. Although most of the diorite has intruded concordant with the bedding of the sedimentary rocks, small discordant bodies of diorite and porphyritic andesite have been observed cross-cutting the sedimentary rocks. Such discordant bodies are exposed 1-1/4 miles due south of Ruby where they cut the Oro Blanco conglomerate and the limestone members. Some of the diorite near Bartlett Mountain in the southern part of the district is likewise discordant to the sedimentary beds. The Ruby diorite sill reaches a maximum thickness of about 2,500 feet in the area just north of the Ruby-Nogales road, but in most areas it is much thinner averaging about 1,500 feet in thickness.

The Ruby diorite intrudes the Cobre Ridge tuff and the overlying Oro Blanco formation. It was emplaced prior to the formation of the northwest-striking fault system. These relationships suggest that the diorite is probably of Middle or Late Cretaceous age.

One mile south of the Montana mine a thin sill of porphyritic hornblende andesite intrudes the limestone member of the Oro Blanco formation. Although texturally dissimilar to the Ruby diorite, this rock has similar structural relations.

This rock is dark green and contains phenocrysts of hornblende and altered plagioclase in an aphanitic matrix. Under the microscope the rock is seen to consist of a fluidal textured matrix composed of plagioclase microlites, phenocrysts of carbonate-altered plagioclase, and hornblende. This rock is probably just a chilled variety of the Ruby diorite.

The diorite has a linear preferred orientation of its hornblende phenocrysts that is the only readily visible flowage structure. Although this lineation is present in much of the rock only a few measurements of its attitude have been made. In general this strikes northwest and is nearly horizontal.

Tertiary Rocks

Sidewinder Quartz Monzonite

The Sidewinder quartz monzonite was originally called Sidewinder diorite porphyry by Fowler(1938) who states that the name was derived from usage by the miners at the Montana mine, where dikes of this rock cut through and follow the ore zones. Study of this rock on a district scale in this investigation, as well as petrographic work, shows that it is compositionally a quartz monzonite porphyry, hence the renaming of the rock. The quartz monzonite is a very widespread dike rock in western Santa Cruz County. This rock is especially abundant in the Oro Blanco district, but has been observed northwest of the present study area in the northern and western parts of the Fraguita Peak area (Reed 1967-kersantite dikes) and as far southeast as section 33 on the north slope of the Pajarito Mountains.

In hand specimen the quartz monzonite seems to be a coarsely porphyritic quartz diorite which has a gray aphanitic matrix. It is rich in phenocrysts of cloudy, partially resorbed quartz 3 to 5 mm across, chalky-altered plagioclase phenocrysts up to one centimeter in length, and numerous chloritized biotite books. Sparse, large sanidine phenocrysts 1 to 3 centimeters in length are found, most specimens however, lack these. Sidewinder dikes generally are less resistant to weathering than their wall rocks and tend to form saddles and gullies. They weather to spheroidal brownish-yellow boulders.

In thin section the rock is seen to consist of a finely crystalline groundmass of quartz and potash feldspar and abundant phenocrysts of sericitized andesine, strongly embayed quartz, and thoroughly chloritized biotite. The groundmass usually contains liberal amounts of fine-grained sericite, carbonate blebs, chlorite, and veinlets of epidote. No sulfide minerals have been observed in this rock. The approximate modal composition based on point counting 2 thin sections is given below:

Quartz phenocrysts	5%
Andesine phenocrysts	28
Groundmass of quartz & potash feldspar	56
Chlorite (after biotite)	5
Carbonate	2
Epidote	<1
Sericite	4

In the Oro Blanco district the Sidewinder quartz monzonite occurs principally as west-northwest and northwest-striking, flat northward dipping dikes. These rarely dip at angles over 40 degrees and most commonly dip at 20 to 30 degrees. The dikes are rarely bounded by planar walls, but instead pinch and swell erratically from a few inches to several tens of feet thick. The maximum observed dike thickness is nearly 300 feet, but the average is about 10 to 50 feet.

In addition to dikes of Sidewinder quartz monzonite there are several exposures of volcanic rocks which, though finer grained, strongly resemble the Sidewinder dikes. This fine-grained rock is especially abundant in the lowest member of the Montana Peak Formation where it occurs as tuff-breccia. A good exposure of this is on the northern slope of the hill just east of the Black Diamond prospect. Here cobbles and pebbles of Sidewinder quartz monzonite are set in a tuffaceous matrix of the same composition.

In the east central part of section 17, T 23 S, R 11 E, two dikes of Sidewinder quartz monzonite can be traced into a foliated tuffaceous rock that strongly resembles the dikes, but which seems to be a nearly horizontal unit and a part of the basal member of the Montana Peak Formation. In addition, several large patches of this rock may be in part extrusive and in part, intrusive. These patches lie mainly in sections 8 and 17, T 23 S, R 11 E, and just to the northeast of the Montana mine.

Dikes of Sidewinder quartz monzonite have been observed cutting rocks as young as the basal member of the Montana Peak Formation, but are cut by Tertiary rhyolite dikes and Blue Ribbon andesite dikes.

Blue Ribbon Andesite

The Blue Ribbon andesite of Tertiary age was first named by Fowler(1938) who called it Blue Ribbon diorite. Examination of outcrops and thin sections of this rock show that it is a hornblende andesite rather than a diorite. The name Blue Ribbon is derived from the characteristic bluish coloration of the outcrops of this rock. This rock is exposed only near the Montana mine.

In hand specimen the Blue Ribbon andesite consists of a flaggy, bluish-green hornblende andesite having a good linear preferred orientation of the hornblende needles. White feldspar phenocrysts are visible, but are sparse and very badly altered.

Under the microscope the rock is seen to consist of a groundmass of plagioclase microlites having strongly developed fluidal texture, altered phenocrysts of plagioclase, and altered phenocrysts of hornblende. The plagioclase has been replaced by carbonate and epidote; and the hornblende has been replaced by chlorite. The matrix is rich in very fine grained magnetite.

The Blue Ribbon andesite has been found only in dike-like form, and only near the Montana mine. The andesite occupies three nearly vertical dikes in the Montana mine area that have been mapped by Fowler(1938). Fowler states that the dikes are present in the mine area and in a large area south of the mine. Work by the present author shows that much of the Blue Ribbon diorite to which Fowler refers is instead the fine-grained facies of the older Ruby diorite. The fine-grained variety of the Ruby diorite and the Blue Ribbon andesite do resemble each other very strongly, but have distinctly different structural relationships. The Ruby diorite has been cut by large displacement faults and has been intruded by the Sidewinder quartz monzonite, whereas the Blue Ribbon andesite has not been faulted significantly and is younger than the Sidewinder quartz monzonite.

The relationship of the andesite to rocks younger than the Sidewinder quartz monzonite is unknown. Based on the intermediate composition it is unlikely that the andesite is genetically related to any of the Tertiary rocks except the Montana Peak Formation. For this reason these are considered to be equivalent in age to the Montana Peak Formation, and most likely are genetically related to the andesites in the lower part of the lower flow member.

Rhyolite Dikes

Tertiary rhyolite dikes are especially abundant in the southwestern part of the Oro Blanco district where they form a major northwest-striking dike swarm about one and one half miles in width. This is traceable for at least 6 miles across the International Boundary to the southeast and at least as far as the Mildred Peak area in the Baboquivari Mountains 24 miles to the northwest. These dikes are the youngest intrusive rock in the district, cutting units as young as the tuff member of the Atascosa Formation.

Compositionally the dikes are classed as porphyritic rhyolite. They consist of two textural varieties, a porphyritic rhyolite with a microspherulitic groundmass, and a porphyritic rhyolite which is distinctly tuffaceous. The two varieties seem to be the same age.

The first variety forms pink, blocky-jointed dikes which have a weak flow structure. The rock consists of a microcrystalline pink groundmass of sperulitic cristobalite and potash feldspar with phenocrysts of sanidine and partially resorbed quartz 3 to 5 mm across. The composition based on point counting one thin section is:

Quartz phenocrysts	3%
Groundmass	87
Sanidine	10
Biotite	<1

The tuffaceous variety tends to form flaggy, thinly laminated dikes which weather to a gray ashy-looking surface. In hand specimen the rock has a light gray aphanitic matrix and tiny broken phenocrysts of quartz and plagioclase. In thin section the matrix is seen to consist of quartz and potash feldspar microlites. Phenocrysts of quartz and andesine, 1 to 2 mm in length, are embayed by the matrix and many seem to be broken crystal fragments. Much of the quartz shows undulatory extinction and may be xenocrysts. The composition based on point counting of one thin section is:

Quartz phenocrysts	8%
Andesine phenocrysts	9

Groundmass	82
Accessory minerals	1

Dikes of rhyolite generally are 10 to 20 feet in width although they range from a few inches to nearly 300 feet in width. They tend to have sharp contacts and slickensided walls. Near irregularities in the walls very complex flow folds have developed.

Most of the dikes have a northwest strike and dip steeply, generally to the northeast. Exceptions to this attitude lie just west of Bartlett Mountain where north-northeast striking dikes have been emplaced, and in the area south and east of Bartlett Mountain. The north-northeast striking dikes generally cut the northwest-striking ones although they are both of similar composition.

In addition to dikes the rhyolite forms three elongated dike-like plugs, and a volcanic neck, all of which lie on a northwest-trending line, and a small isolated plug. The largest two plugs lie in the west central part of the district. They consist of nearly vertically dipping dike-like bodies of rhyolite emplaced with their long axes oriented northwest. These two are separated by a northeast-striking fault, but it is uncertain if the apparent offset between the two bodies is due mainly to movement on the fault or to original emplacement that was dammed by gouge in the fault zone. The third plug forms the core of Bartlett Mountain in the south central part of the study area. This plug is less elongated than the other two but is interconnected with many thick dikes which emanate from the plug to the northwest and southeast.

This plug has nearly vertical flow structure which conforms to the contacts. It intrudes all of the Mesozoic rocks and a small patch of the tuff member of the Atascosa Formation near the top of Bartlett Mountain.

One and one half miles southeast of Bartlett Mountain the rhyolite occupies a small volcanic neck. The neck is crudely elliptical in shape with its long axis oriented northwest-southeast. On the northwestern end a small rhyolite flow extends for a short distance from the neck. Within the neck, especially near its borders, flow structure is very well developed and dips steeply parallel to the steeply dipping contacts. Along the northern contact, which is well exposed, lies a nearly vertically dipping glassy zone which ranges from 4 to about 12 feet thick. This consists of a reddish-brown vitrophyre containing sparse white phenocrysts of plagioclase.

The neck exhibits a striking topographic form. It consists of a light gray spire about 150 feet in height whose shape is strongly controlled by foliation attitudes (Figure 11).

About 2 miles north of the Ruby camp lies another small rhyolite plug. This intrusive mass is 250 by 800 feet in plan with the long axis oriented nearly north-south. It has been observed intruding only the Cobre Ridge tuff so that its relationship to other rock units is unknown.

The rock comprising the plug is far more silicious than the other Tertiary rhyolite in the Oro Blanco district and may be unrelated to the Tertiary rhyolite. In hand specimen the rock is a

Figure 11. Volcanic Neck Composed of Tertiary Rhyolite

This forms the prominent spire in the central part of the photograph. Dark colored hills in background are underlain by Montana Peak Formation. Light colored hills in background are composed of Atascosa Formation.

yellowish-brown quartz porphyry having a very strongly silicified aphanitic matrix. Quartz phenocrysts 2 - 4 mm in length are generally the only visible phenocrysts. Locally the rock is strongly iron-stained from the weathering of a small amount of disseminated pyrite.

STRUCTURE

District Structure

The structure of the Oro Blanco mining district is characterized by large displacement normal faults which cut southwestward-dipping sedimentary and igneous rocks of pre-Tertiary age. The faults have three dominant strikes, north-northeast, northeast, and northwest. Nearly all are normal faults or high angle reverse faults that have very small strike-slip components of movement and displacements ranging up to 10,700 feet. Most of the movement on these structures took place during the Laramide orogeny, but minor late displacements are at least as young as mid-Tertiary.

Other structural features in the district include several open southward-plunging folds in the Oro Blanco formation.

North-Northeast Faults

Faults having a north-northeast strike are most abundant in the central and eastern parts of the Oro Blanco district. The strikes range from N 0 to 30° E in general, although some of these features bend eastwards on their southwestern ends to form curved traces that are concave to the east (Figure 3). Dips are steep, generally over 70 degrees, both eastward and westward.

Faults of this orientation are the oldest in the district. They offset all of the pre-Tertiary rocks, but have larger apparent displacements in the Cobre Ridge tuff than in the overlying Oro Blanco formation. The bedding attitudes in the Oro Blanco formation and the underlying volcanic rocks are similar so that some displacement must have occurred prior to deposition of the Oro Blanco formation. This relationship may be seen on the fault which lies in the north-northeast-trending part of Warsaw Canyon (Figure 3).

With few exceptions the relative movement on the north-northeast faults is eastern side relatively downthrown. The first period of movement on these structures was before deposition of the Oro Blanco formation so that it must have preceded the southwestward tilting of the units. Thus, what may have been a normal fault prior to the 60 to 70 degree tilting may now appear to be a strike-slip fault.

The most recent movement on the north-northeast striking faults is older than the Sidewinder quartz monzonite, but younger than the emplacement of the Ruby diorite.

Northeast Faults

Northeast faults are very abundant in the northern and western parts of the district (Figure 3). They are especially common in the Oro Blanco formation in the area of the Oro Blanco settlement. Generally these are steeply-dipping normal faults having the northwest sides relatively downthrown. They are younger than the initial movements on the north-northeast faults, but significantly displace rocks no younger than Ruby diorite. These faults clearly have experienced at least two major periods of movement and one minor very young period of movement. The two major periods of movement are separated by large displacements along northwest faults. The largest observed displacement on a fault of this orientation is on one which passes just south of Oro Blanco settlement. This fault shows evidence for two periods of movement. The block of Oro Blanco formation that lies on the southwest slope of Cobre Ridge (Figure 3) could reach its present position only if movement occurred on the northeast fault prior to repetition of the section by the northwest fault that is now occupied by a large rhyolite intrusive body. On the other hand, the northeast fault clearly offsets two large displacement northwest faults.

Using only a normal component of movement, which is reasonable from the apparent displacements of opposite dipping beds, this northeast fault has a total displacement of about 10,700 feet, most of which preceded the development of the northwest faults.

The final movement on the northeast faults is at least younger than the emplacement of the Tertiary rhyolite dikes. Such movements have slightly sheared a large body of rhyolite on the west slope of Cobre Ridge. Other evidence for late movement on these structures is the shearing of ore zones and Sidewinder quartz monzonite dikes by faults of northeast strike.

Northwest Faults

Large displacement northwest normal faults lie in two belts in the Oro Blanco mining district. The northern belt lies on the northeast slope of Cobre Ridge and extends from the southwestern slope of Montana Peak to the Altar Valley, 17 miles to the northwest. At both ends this structural zone is covered by younger rocks and alluvium so that its total extent might be much greater. The southern belt lies on the southwestern slope of Cobre Ridge within a large swarm of Tertiary rhyolite dikes. This zone extends at least from the International Boundary to the Altar Valley. A structural zone of like trend and possessing rhyolite dikes similar to those in the swarm has been seen by the author in the Mildred Peak area in the Baboquivari Mountains. These dikes lie on the northwestward projection of the zone at Oro Blanco. If this in fact is the same structural zone, then it would extend over a distance of more than 32 miles.

The northern belt consists of two large normal faults and several minor faults which seem to be branches of the major ones. Both major faults strike northwest and dip at moderate angles to the northeast. The more northeasterly fault strikes from N 70° W to N 15° W and usually dips 48 to 70° northeast, although a few steep southwest dips have been found. This structure splits at the southeast end with one branch forming the Montana vein and the other passing along California gulch. The southwestern fault strikes N 30° W to N 53° W and dips from 40 to 90° northeast. The northeastern fault has a stratigraphic throw of about 6,900 feet, whereas the southwestern one has a stratigraphic throw of over 10,000 feet. The latter figure may be in error however, because of possible undetected repetition of the Cobre Ridge tuff section by normal displacement along Sidewinder quartz monzonite dikes. If such repetition has taken place then the stratigraphic throw may be somewhat less than 10,000 feet. The actual net slip on these faults is about the same as the stratigraphic throw. Only a small component of strike-slip movement in a left lateral sense is evident on these structures as is shown by the positions of the nearly north-south steeply-dipping western contact on faulted segments of the Ruby diorite.

The southern belt contains a greater number of faults, but they are mostly of relatively small displacement compared to those of the northern belt. The stratigraphic throw across the total width of the southern belt is about 8,300 feet with the northeastern side relatively downthrown. The displacement of the folded limestone member of the Oro Blanco formation just southeast of Bartlett Mountain (Figure 3) again shows that the movement on the faults is mainly dip-slip with only a minor strike-slip component.

Faults of the southern belt are more poorly exposed than those in the north so that fewer direct observations of their dip are possible. Nevertheless faults of the southern belt in general seem to dip more steeply than those in the northern belt. Dips range from 50 to 90° with dips about 80° being most common. In addition many small displacement faults in this belt are now occupied by Tertiary rhyolite dikes which dip vertically or steeply northeastward.

Some of the northwest-striking faults, especially those in the northern belt, have experienced renewed movement which post-dates the emplacement of the Sidewinder quartz monzonite dikes and displaces slightly units as young as the lower dacite tuff member of the Montana Peak Formation. The displacement is generally in the same relative sense as the older movements but much smaller, only a few tens of feet at most. It is recognized by shearing of Sidewinder dikes and by brecciation of mineralized zones that post-date the earlier movements.

The relationships of the northwest-striking faults to the various rock units in the district are summarized on the Interpretative Geologic Cross Sections (Figure 12).

Folds

Broad open folds are fairly common in the Oro Blanco formation. Such structures are best developed on the lowlands surrounding Oro Blanco settlement. Here the Oro Blanco formation has been folded into a fairly open southwestward-plunging anticline and syncline. On all sides of the Ruby diorite exposures southeast of Oro Blanco settlement the sedimentary rocks bend to conform to the intrusive contacts. Northwest of Oro Blanco the beds maintain a fairly uniform northwest strike interrupted only by drag along northeast faults. A similar situation exists in the area near Bartlett Mountain where the many faulted segments of the diorite-Oro Blanco formation contact are conformable to folded bedding in the sedimentary rocks. These spatial relationships of folds to the diorite suggest that the folds owe their origin to forceful emplacement of the diorite.

In the southeastern part of the district the actual cause of folding is obscure. Here a tight diapiric anticline in the limestone member of the Oro Blanco formation has pierced a warped, but unfolded sequence of overlying sandstones and siltstones (see Figure 3, section 20,T 23 S, R 11 E). The limestone has been folded into a tight southeast-plunging syncline and a tight nearly isoclinal diapiric anticline that also plunges southeast. Beds of sandstone underlying the limestone are only gently folded and those overlying it within the core of the syncline are unfolded. Abundant cut and fill structure in the sediments overlying the limestone indicate no overturning of the beds nor any significant change in the attitudes of the beds. No faults have been observed between the limestone and overlying units so that the limestone must have intruded across the overlying beds to form a diapiric anticline.

Minor folds are fairly common in the finer grained beds of the Oro Blanco formation particularly in the north central part of section 17, T 23 S, R 11 E (Figure 3). Here purple siltstones and fine-grained sandstones have been crumpled into a very chaotic mass of small folds which seem to have no relationship to nearby faults or intrusive bodies. Perhaps these folds as well as the diapir discussed above were formed by gravity sliding during southwestward tilting of the beds.

Recent Structure

Only one structural feature seems to have formed in Recent time within the Oro Blanco district. This is a large landslide block involving the upper two members of the Montana Peak Formation on the west slope of Mule Ridge. Here a slide block measuring 2,600 feet by about 1,300 feet in plan has slid an estimated 200 feet down the escarpment of Mule Ridge. Several other slide blocks were observed along this escarpment, but these are very small.

Regional Structure

In an attempt to determine the causes for the large displacement faulting in the Oro Blanco district the author undertook a reconnaissance investigation of the geology of selected parts of western Santa Cruz County and south-central Pima County. This involved compilation and field checking of existing geologic data, as well as regional geologic mapping to fill in critical areas not covered by previous work. In addition photogeologic interpretation was used to obtain the attitude and distribution of the relatively flat-lying Tertiary rocks.

The areas investigated include parts of the Cerro Colorado, Pajarito Mountains, Guijas Mountains, and the Oro Blanco Mountains. Brief visits were made to the western side of the Sierrita Mountains and the east central Baboquivari Mountains to examine the stratigraphic sections. Figure 13 is a compilation of all published data modified and suplimented by the author's own observations.

Fraguita Peak Area, Oro Blanco Mountains

The geology of the Fraguita Peak area was mapped by Reed (1967) during a study of the structure and petrography. This area adjoins the present study on the northwest. Reed interprets the area as being composed of Cretaceous(?) sedimentary rocks which have been intruded by a large mass of Tertiary(?) quartz latite. Reed mapped no large displacement faults, but explains the outcrop patterns by stating that the quartz latite intruded the Oro Blanco Conglomerate even though the conglomerate consists of pebbles of the quartz latite. A brief reconnaissance of Reed's map area reveals that the quartz latite does not intrude the conglomerate. Instead the conglomerate lies upon an erosional surface on the quartz latite. The outcrop pattern shown by Reed has been produced by repetition of the stratigraphic section by northwest-striking, northeast dipping normal faults. These faults have offset older northeast faults and in turn have been offset by younger northeast faults. Several of these faults have been observed in the numerous prospect pits within Reed's study area.

In the southwest part of Reed's mapped area is a swarm of Tertiary rhyolite dikes that is very similar to those in the swarm of the present study area. These are merely a continuation of the same dike swarm. A further continuation of this swarm is visible on aerial photographs 2-1/2 miles northwest of Reed's map area. These dikes are sketched on Figure 13.

In summary the same structural pattern is manifest in the area directly northwest of the Oro Blanco district.

Las Guijas Mountains

The Guijas Mountains lie north of the village of Arivaca seven miles north-northwest of Oro Blanco settlement. The range consists of a southwestward tilted block of Cobre Ridge tuff that is overlain by Oro Blanco formation and intruded by a leucogranite or quartz monzonite at the northwest end. The granite is older than the Oro Blanco formation and may correlate with the Warsaw quartz monzonite.

Most of the range consists of a single block of Cobre Ridge tuff that is bounded on the south by a slightly sheared depositional contact with overlying Oro Blanco formation, and on the north by a major northwest fault contact with Oro Blanco formation sandstones and siltstones. The fault marking the northern edge of the block has a minimum stratigraphic throw of 11,000 feet, relatively downthrown on the northeast. On the northeast corner of the range and in a group of unnamed hills east of the Guijas range are other faulted blocks which exhibit the same southwestward-dipping stratigraphic section, that is, Cobre Ridge tuff overlain by Oro Blanco formation. These likewise have been emplaced by large displacement northwest-striking faults having the northeast side relatively downthrown.

Except for the apparent lack of major northeast faults, the structure of the Guijas Mountains is quite similar to that at Oro Blanco. This is not to say that the northeast cross faults are not present in the Guijas range for the numerous northeast veins would refute this. Instead this direction is merely more subdued here than it is to the southeast.

Pajarito Mountains

The Pajarito Mountains lie about 8 miles southeast of the Ruby camp. They are a northwest-trending range consisting of ash flow tuffs that are here correlated with the Cobre Ridge tuff. Nelson(1963) studied the southeastern end of this range in the Peña Blanca and Walker Canyon areas. He finds that the tuffs dip northeast and are overlain by Oro Blanco Conglomerate that also dips northeast. The present author made a brief visit to this area and found that at least the tuffs on the northern flank of the range are dipping southwest instead of northeast as indicated by Nelson. The foliation measured by the author is only sparingly developed and consists of slightly flattened inclusions and pumice fragments indicative of incipient welding. It seems that the northeast-dipping foliation attitudes shown by Nelson may be the attitude of a very strongly developed sheeting that the author observed in Peña Blanca Canyon. Sparse eutaxitic structure in the tuff along a jeep trail 2 miles west of Nelson's map area and along the Ruby road indicates that the tuffs do indeed dip southwest. The bedding in the overlying sedimentary rocks in general dips northeast however, similar to that shown by Nelson at Peña Blanca.

Nelson shows one northwest-striking fault downthrown on the northeast in the area just south of Castle Rock (Figure 13) and indicates in his report that a major fault of this orientation may lie along the Ruby road at the north edge of the Pajarito Mountains. The other major fault direction shown by Nelson is represented by a series of mineralized northeast fissures.

The large angular discordance between Oro Blanco formation and the underlying tuff presents a serious problem to working out the structural history of the region. It requires that the tuffs be tilted prior to deposition of the conglomerate, whereas the same amount of tilting occurred at Ruby only after deposition of the conglomerate. It further requires a northeastward rotation after deposition of the conglomerate that is contrary to the rotation of the beds several miles northwest along strike. Nelson(1963) states, regarding the contact between the Pajarito lavas and the Oro Blanco formation, p. 24:

> "An irregular layer of silicified tuff locally separates the Pajarito lavas from the Oro Blanco Conglomerate. This tuff layer probably was deposited upon an old erosion surface of the lavas, as its thickness varies greatly in different exposures. The tuff is usually apple-green with scattered patches of pink, and is cut by many veinlets of vuggy quartz."

Another interpretation of this tuff zone on the contact is that it is a silicified fault breccia. No similar tuff zone has been found anywhere in the Oro Blanco district. It is possible that the exposures of Oro Blanco Conglomerate and the overlying fine-grained beds form the allochthonous block of a gravity glide sheet that has been displaced out over opposite dipping volcanic rocks. The contacts between the Pajarito lavas and the conglomerate observed by the author have been very poorly exposed so that the presence of a fault could not be ascertained. Such a flat-dipping fault could explain very well the discordance of dips between the conglomerate and the volcanic rocks. Certainly more work needs to be done before this problem can be solved.

Cerro Colorado Mountains

The geology of that part of the Cerro Colorado Mountains which is underlain by Mesozoic rocks has been described by Jones(1957) and Davis(1955). The author visited only a small part of this area so that the geology shown for this area in Figure 13 is mostly the work of Jones and Davis. Rocks exposed here include a quartz latite tuff which probably correlates with the Cobre Ridge tuff, a thick arkosic sandstone unit apparently interbedded with the tuff, and an overlying sequence of conglomerate with minor limestone and shale. Much of the area has been covered with a mantle of Tertiary(?) andesite. In the eastern part of the district the volcanic rocks and interbedded sandstone strike north-northwest and dip steeply southwest similar to that in ranges to the south. Davis, who worked in the western part of the Cerro Colorado district, shows no attitudes in either the volcanic or sedimentary rocks although it is very probable that they too dip towards the southwest. Faulting in the Cerro Colorado district is along northwest and northeast directions similar to that in the south, but a nearly east-west direction of faulting is present here as well.

Sierrita Mountains

A large area on the west side of this range has been studied by Thoms(1965). A highly generalized map of Thoms' work is Figure 14.

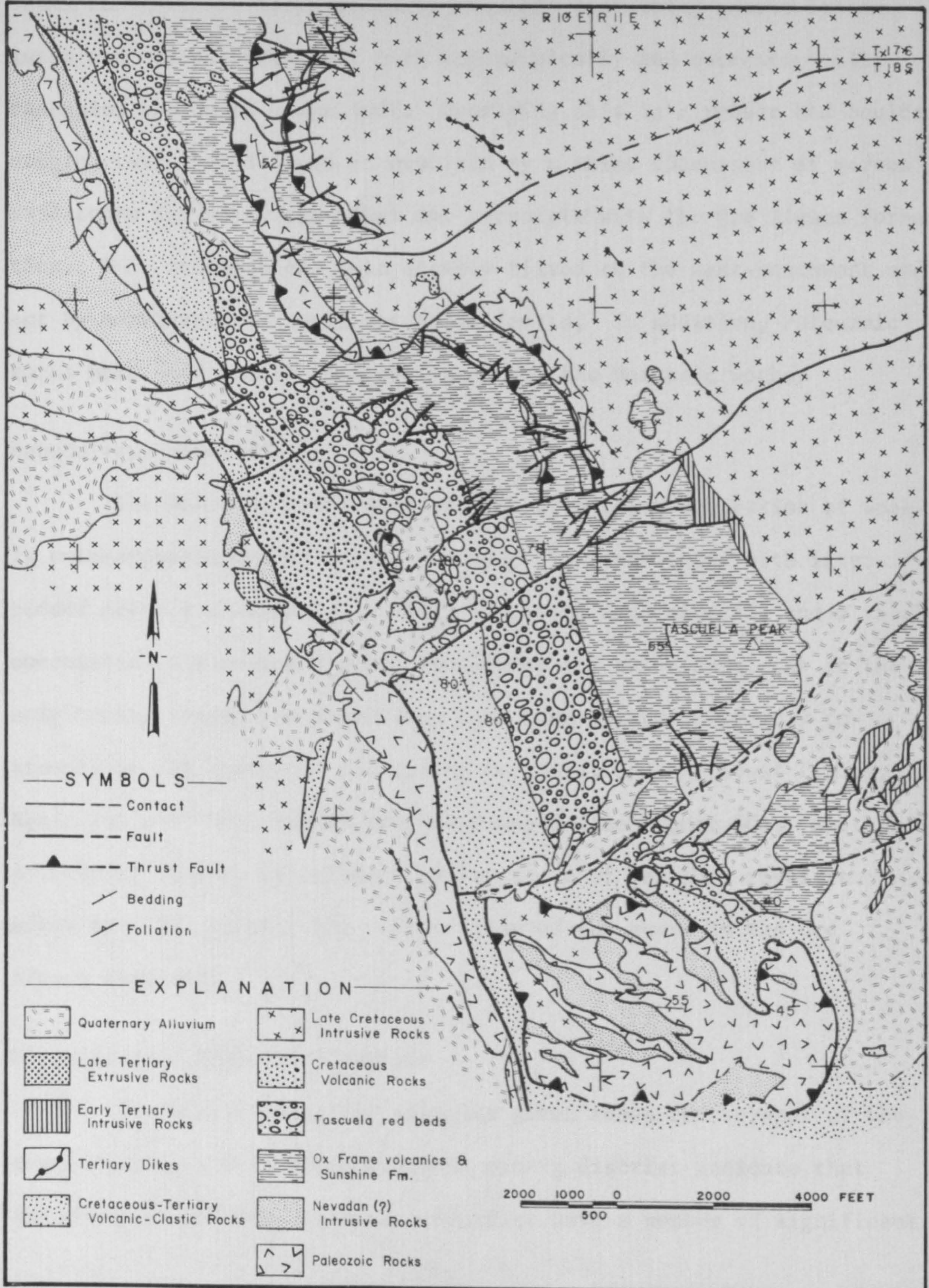


Figure 14. Geologic Map of the Tascuela Area, Sierrita Mountains (Thoms, 1965)

Thoms recognizes a thick volcanic sequence containing quartz latite tuffs and welded tuffs that both megascopically and microscopically resembles the Cobre Ridge tuff. Overlying this is a pebble and boulder conglomerate that in turn is overlain by a thick succession of maroon sandstones and siltstones that may correlate with the Oro Blanco formation. This sequence has been steeply tilted to the west-southwest and cut by northeast and north-northwest faults. In addition, Paleozoic rocks have been thrust southwestward over the Mesozoic rocks.

Baboquivari Mountains

The Mesozoic rocks here consist of a thick succession of weakly metamorphosed quartz latite porphyry flows and tuffs with interbedded arkosic sandstones, a thick overlying conglomerate, and a thick succession of maroon and green sandstones and siltstones. As in the neighboring ranges the formations have been tilted moderately to steeply to the southwest and cut by northwest and northeast faults. Again the northeast faults are the younger (see Figure 10). Another structural feature of interest is the swarm of Tertiary rhyolite dikes that is probably the continuation of the swarm in the Oro Blanco district.

Discussion of Regional Structure

The brief geological sketches given above for several of the mountain ranges near the Oro Blanco mining district indicate that these ranges and the Oro Blanco district have a number of significant structural features in common. These are:

1) The presence of stratigraphic units which are very similar in appearance, composition, thickness, and order of deposition.
2) The units have all been tilted to the southwest or west-southwest at moderate to steep angles.
3) Faults of two major strikes dominate, northwest and northeast.
4) Generally the northeast faults have displaced the northwest faults.
5) Extensive repetition of the stratigraphic section has occurred in some of the ranges through large displacement on normal faults.
6) Although one thrust fault is known and minor folds are present in a few areas, the dominant mode of rock failure has been by normal faulting.

A very homogeneous structural pattern therefore is present in the Mesozoic rocks within a large part of southern Pima County and Santa Cruz County. Figure 15 is an overlay of the Pima and Santa Cruz County Geologic Map (Wilson, Moore, and O'Haire 1960) showing attitudes in Mesozoic and Paleozoic rocks and the traces of major faults.

The data for the map have been compiled from numerous sources but mostly from University of Arizona theses. In compiling the map an attempt was made to establish the dominant structural attitude of bedding (or foliation, in the case of volcanic rocks) for each mountain range. Those areas where complex folding has occurred have been left blank. The data in the southwest are sparse due to lack of work in the Papago Indian Reservation.

No attempt has been made to distinguish Tertiary faults from those that are older. It has been assumed that most major faults have been active over a large span of geologic time, so that many of the Tertiary faults may have been active in Mesozoic time. In preparing Figure 15 no effort has been made to rotate out tilting caused by Tertiary structural activity.

Several points are apparent from examination of Figure 15:

1) The area can be divided roughly along a northwest line into two homogeneous domains, one having generally north and east dips, the other having generally south and west dips.
2) The dominant directions of fault strikes are northwest and northeast.
3) In the southwestern domain the northwest faults are generally downthrown on the northeast whereas in the northeastern domain the northwest faults are downthrown on the southwest.
4) Attitudes in Cretaceous rocks in the Santa Rita Mountains near Patagonia suggest that the division between the two domains is really the crest of a dome. A

similar conclusion is reached for the Roskruge Mountains-Dobbs Buttes area also on the dividing line where the structure has been defined as a broad southeast plunging dome (Arizona Geological Society 1955, p. 255).

Origin of District and Regional Structure

Any hypothesis for the origin of the geologic structure of the Oro Blanco mining district must also explain the similar structural patterns that have developed on a regional scale. The hypothesis must also explain the symmetry shown by the two structural domains as described in the four points in the preceding section.

Importance of Crustal Tension

Considerable crustal extension is apparent in the region between the International Boundary and the Cerro Colorado Mountains. The geology along a cross section trending at right angles to the strike of the northwest faults is sufficiently well known in the area from the Cerro Colorado Mountains to the International Boundary to enable one to calculate the amount of crustal extension caused by the faulting. Three major northwest fault zones are involved in making this calculation, two of them in the Oro Blanco district and one at the northeast edge of the Guijas Mountains. The stratigraphic displacement on these faults totals about 36,000 feet over a line of section 15 miles in length. All of the faults are downthrown in the same sense, that is, on the northeast side. In general the rocks cut by the faults strike parallel to the northwest faults and dip at nearly right angles into the faults. The faults have been shown to have small strike-slip components of movement. Using these conditions one can state that the net slip on the faults is about the same as the stratigraphic throw, that is 36,000 feet. Using an average northeastward dip of 50 to 60° for the faults one obtains a lateral extension of the surface of 18,000 to 23,000 feet over a distance of 15 miles, a 23 to 29 percent extension of the upper crust. Laterally directed crustal tension (or at least a reduction of the lateral stress to a value less than the vertical stress due to gravity) must have been active here to produce such large extensions of the crust and seems to be responsible for the formation of the large displacement normal faults.

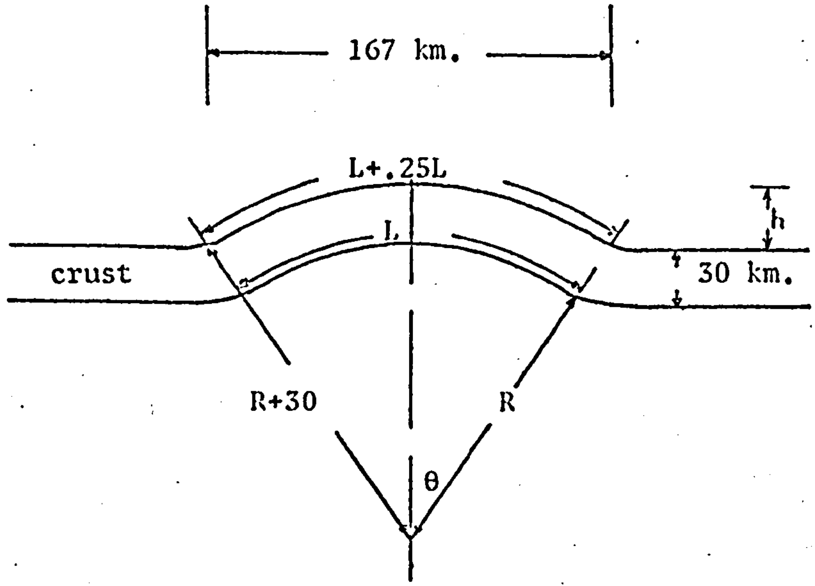
Evidence for Doming and Collapse

Two areas shown in Figure 15 lie on the boundary between the two structural domains which suggest the presence of a dome, the Roskruge Mountains and the Santa Rita Mountains. The Roskruge Mountains have been described in the literature (Arizona Geological Society 1955, p. 255) as being a gentle southeast plunging dome. In the Santa Rita Mountains the flat beds which reverse their direction of dip over the domain boundary suggest a dome here as well. In addition the direction of dip of the rocks in both of the domains is consistent with a domal structure. But examination of the Pima and Santa Cruz County Geologic Map (Wilson, Moore and O'Haire 1960) reveals that there is no core of older rocks in this apparent domal structure. Instead there is extensive repetition of the stratigraphic section as one approaches the crest of the structure from either the northeast or the southwest side. Some of the repetition of the section has been caused by collapse on northwest faults such as those in and near the Oro Blanco district, but much of it has probably been caused by faults of similar orientation that lie buried beneath valley fill between the individual mountain ranges. The picture that emerges is one of a domal uplift which has collapsed to such a degree that there is virtually no net structural relief between the flanks and the crest.

Mechanism for the Formation of the Structural Pattern

There seems to be two possible ways by which the structural pattern of Pima and Santa Cruz Counties could form, by collapse of a domal area or by collapse resulting from regional crustal tension. Both mechanisms involve doming and collapse, however the cause and effect relationships for the two mechanisms differ. In the case of a collapsed dome, tension responsible for collapse results from arching of the dome. In the second case the dome is the result of intrusion by magma and isostatic rise of the area during and after the faulting. Were it not for collapse the first case would result in a dome many times the size of that developed in the second case.

A few simple calculations reveal the magnitude of doming required to produce the necessary amount of extension of the surface. The width of the apparent dome is fairly well represented by the area shown in Figure 15. Northeast of the area shown in Figure 15 the structural pattern changes. Therefore the width of the dome is approximately 100 miles or 167 km. If one uses a crustal thickness of 30 km and an average surface extension of 25% over the full width of the dome, a dome having a radius of 120 km at the base of the crust is required. This domal feature if uncollapsed would have a structural relief of 25 kilometers. Certainly no dome of this magnitude would remain uncollapsed. Collapse would take place simultaneously with the upward warping at the base of the crust. A considerable decrease in upper mantle density would be required to cause the necessary amount of upwarping, for which there seems to be no adequate cause.



$2\pi R = L$

$2\pi(R+30) = 1.25L$

$L = 2\pi(R+30)/1.25$

$2\pi R = 2\pi(R+30)/1.25$

$R = 120$ km

$\theta = \sin^{-1}[167/2(R+30)]$

$\theta = 34°$

$h = (R+30) - (R+30)\cos\theta$

$h = 150 - 150\,(.83)$

$h = 25$ km

The author favors the second explanation, that of regional crustal tension, (discussed below) although both mechanisms would produce the same result. Recent studies on the problems of sea floor spreading based upon studies of the ocean basins point to the significant lateral expansion of the sea floor near the East Pacific Rise and the Mid Atlantic Ridge. A number of workers including Menard(1964) have suggested that the East Pacific rise which vanishes beneath the North American Continent on its northward trend, and whose projected path passes through the Basin and Range Province of Arizona, may be responsible for the abundant magmatism and faulting in the Basin and Range Province. The addition of material from great depth in the mantle to the region near the base of the crust, if localized along a relatively narrow region would cause a zone of crustal tension. An addition of material could be caused by the presently popular mantle convection currents or by a localized relief of stress caused by an expanding earth. The latter explanation has recently been discussed by Egyed(1957) and seems to be the more reasonable explanation based on the limited knowledge we have of the earth's mantle.

The second possible explanation for the observed structure is that of regional crustal tension in which tensional stress, or at least a reduction of the lateral stress to considerably less than the vertical has been localized by a linear crustal weakness. In the case of Pima and Santa Cruz Counties the line separating the two structural domains is considered to be the approximate site of such a zone of weakness.

Early in the development of the structural features the addition of material at great depth beneath the zone of weakness may have initiated a small amount of doming at the surface. This might account for the gently domed areas that lie on the line separating the two structural domains. Another more likely explanation for the doming is that plutonic masses intruding upwards along the zone of crustal weakness have caused the doming. It should be noted that the line between the two domains is the approximate center of several Laramide granitic batholiths, such as in the Patagonia, Santa Rita, and Sierrita Mountains.

On the western side of the Sierrita Mountains an overthrust sheet seems to have developed by thrusting upwards and off to the side of the plutonic core of the range attesting to the forceful intrusion of the granitic masses. As the degree of crustal extension increased in a direction perpendicular to the line separating the two structural domains, gravity faults would form in which the dominant direction of displacement would be downwards toward the initial zone of weakness. If the extension continued long enough, faults would form at progressively greater and greater distances from the centerline. It is readily apparent that in such a collapse structure the existence of planar fault surfaces would result in little tilting of the beds except for antithetic rotation of a few degrees such as is commonly observed on the edges of grabens. In addition some tilting would come about by isostatic uplift of the area of the subsided blocks. In order to produce the more steeply tilted blocks shown in

Figure 15, it is necessary that the fault surfaces be curved and concave towards the center of the collapse feature. If all of the fault surfaces are curved to the same degree however, the beds in the fault blocks near the center will dip much more steeply than those in blocks on the flanks because of progressive formation of the faults outwards from the center. In Figure 15 no such increase in dip is observed near the center of the structure. Instead the dips are very uniform over much of the width of the flanks. This uniformity of dip could be produced only if the faults near the center are nearly planar and those far out on the flanks are curved as illustrated in Figure 16. A highly generalized sequence of formation of the collapse structure is summarized in Figures 16A through 16D.

No mention has yet been made here of the role of the northeast-striking faults that are prevalent throughout much of Pima and Santa Cruz Counties. These structures are generally younger than the northwest-striking faults and may be caused by differential uplift and sinking of sections of the collapsed area, possibly the result of isostatic adjustments. Blocks within the collapsed zone which were either rising or sinking would be free to move at their northeast and southwest sides, but not on the northwest and southeast sides. It is on the northwest and southeast sides that shear stresses would develop and favor the formation of northeast-striking faults. In addition the strong northeast trending structural grain in the Precambrian basement rocks (Wilson 1962, p. 12) would further favor the formation of the northeast-striking faults.

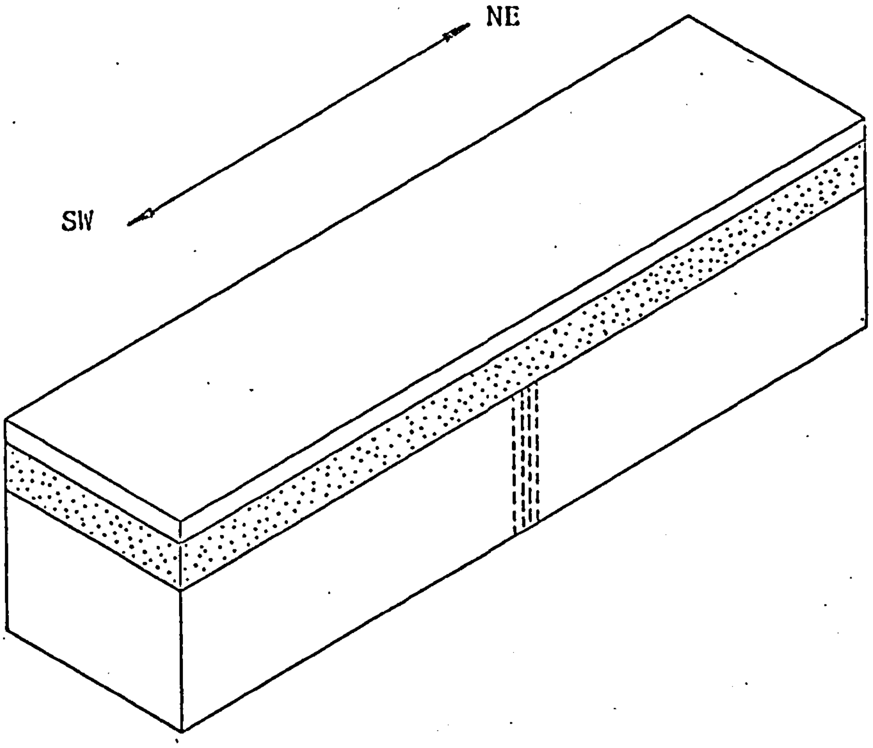


Figure 16. Formation of Collapse Structure

A. The region is subjected to lateral extension along a northeast line. Initial fracturing is concentrated along a northwest-trending zone of weakness in the basement rocks.

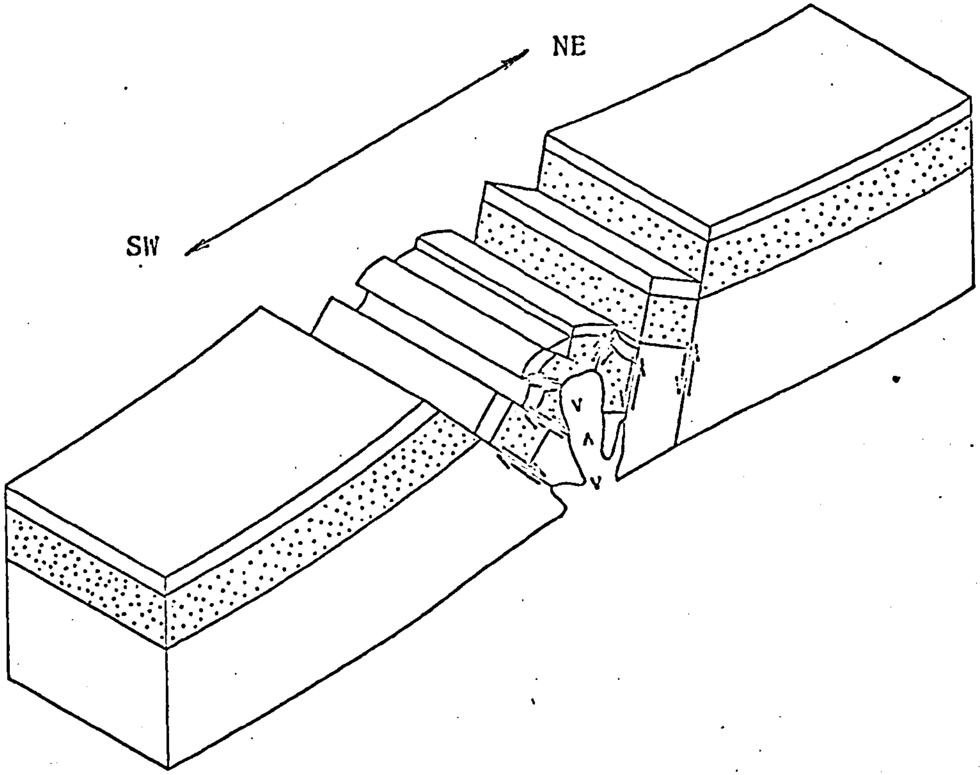


Figure 16. Formation of Collapse Structure--Continued

B. As extension continues, a graben forms followed by additional dropping of blocks progressively farther away from the zone of weakness. Release of pressure due to extension promotes melting of rocks deep in crust. The resulting anatectic magma migrates upwards under buoyant forces. Rocks overlying the rising magma are arched and thrust aside. Isostatic rise of central part of collapse structure as well as doming by magma tilts the beds.

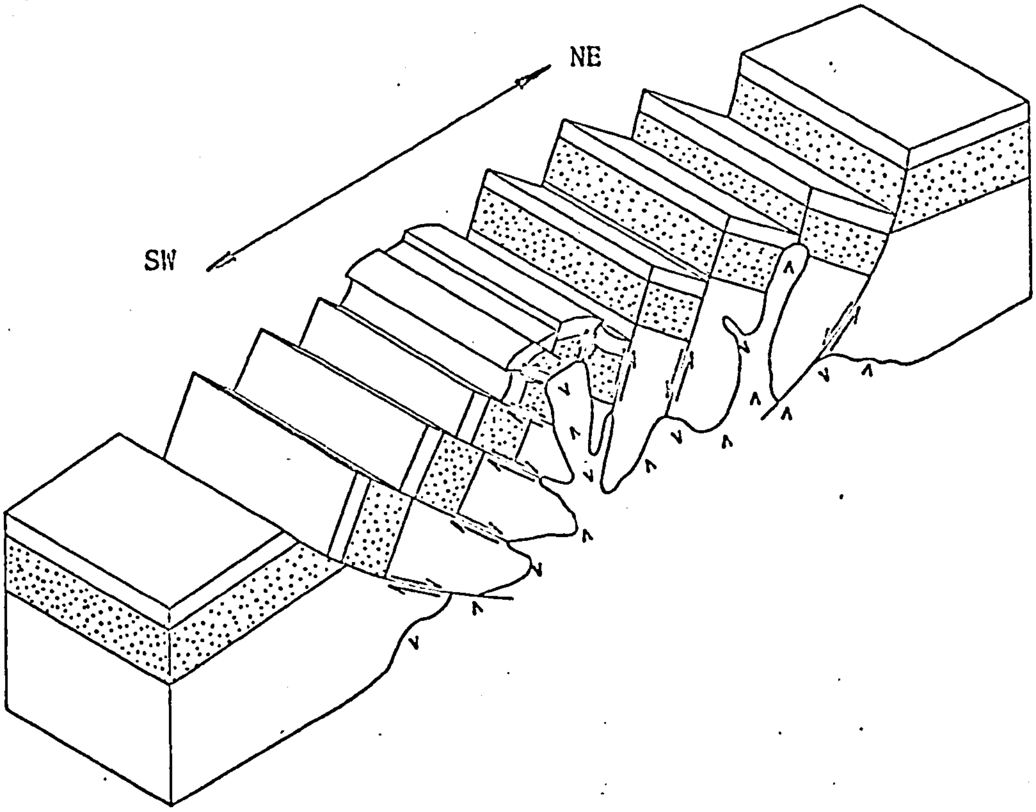


Figure 16. Formation of Collapse Structure--Continued

C. As the extension becomes greater, more magma is generated and mobilized. Faulting downwards towards the center continues. Faults form at the outer edges of the collapse structure which are concave towards the center. Movement along these features causes additional rotation of previously tilted beds.

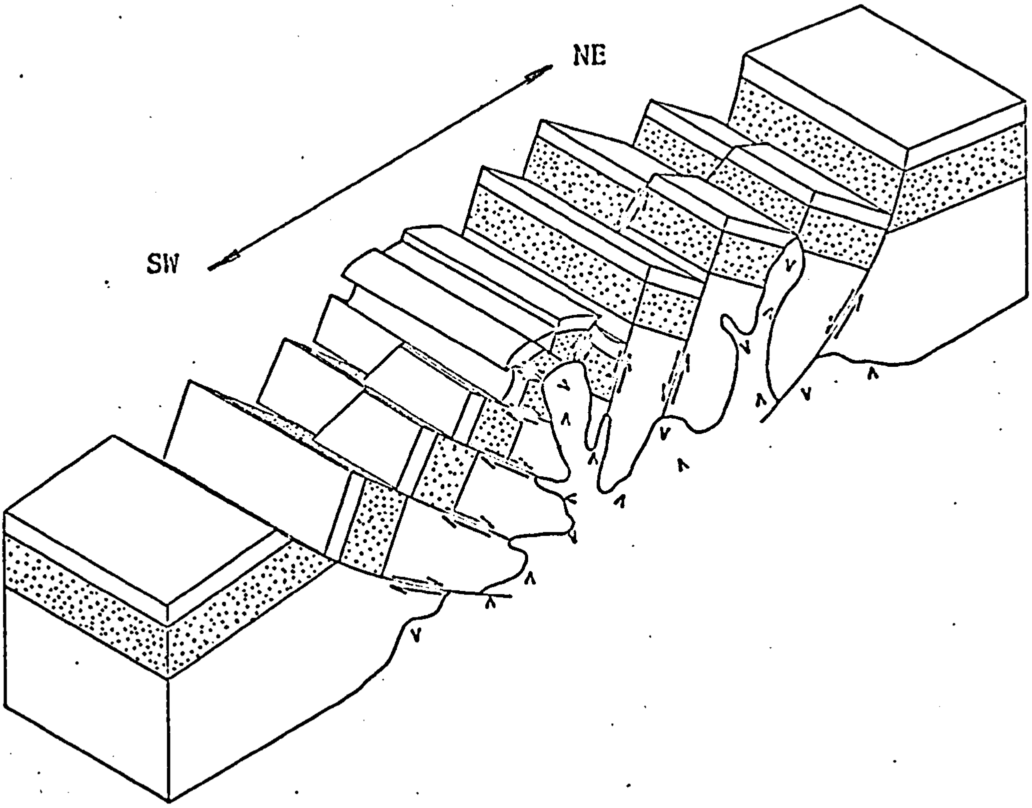


Figure 16. Formation of Collapse Structure--Continued

D. The northeast faults form or are reactivated after most of the movement on the northwest faults has ceased. These faults are probably caused by isostatic adjustments of the blocks in the collapse structure after the lateral extension has ceased. Erosion of the collapsed area results in a dome-like structural pattern characterized by moderate dips and negligible net structural relief from flank to crest.

Age of the Collapse Structure

Detailed study of the relationship of major faulting to the various rock units reveals that the age of the fault displacements is Late Cretaceous to Early Tertiary (Laramide). Although much of the normal faulting in southern Arizona has been ascribed to the Mid-Tertiary Basin and Range orogeny by previous workers, the bulk of the evidence gathered by the present author indicates that the Basin and Range structure of southernmost Arizona was formed in the Laramide orogeny and that only minor adjustments occurred in Mid-Tertiary time. Jones(1966) reaches a similar conclusion for the southeastern part of Arizona in the Tombstone Hills and Mule Mountains.

The Pima and Santa Cruz County Geologic Map (Wilson, Moore, and O'Haire 1960) shows several areas where Tertiary rocks have been tilted such as in the Tucson Mountains and the Sierrita Mountains. It is possible that some of this tilt can be ascribed to the collapse structure, but the author feels that most of this is due to other causes.

In view of the relatively homogeneous nature of the two structural domains shown in Figure 15 and the similarity of the geology of many ranges in southern Arizona to the Oro Blanco mining district, it seems very probable that the collapse structure formed mainly during the Laramide orogeny as did the faults at Oro Blanco. This illustrates once again that the Laramide orogeny of southern Arizona was not characterized mainly by lateral compression, but by reduced lateral stress and gravity effects. Previous workers, notably Mayo(1966) and Jones(1966) have reached a similar conclusion.

Relationship of Lineaments to Southern Arizona Structure

In recent years the subject of lineament tectonics in Arizona has been discussed by several workers, notably Mayo(1958), Schmitt (1966), and Wertz(1966). These authors describe and comment upon the linear alignments of structural features and their relationship to ore deposits. Mayo(1958) describes three northwest-trending lineaments in the Basin and Range province of Arizona, the Walker lane zone in southwestern Arizona, the southwest Arizona belt in the central part of the Basin and Range province, and the central Arizona belt near the northeastern edge of the Basin and Range province.

One of the lineaments, the southwest Arizona belt, seems to coincide with the line separating the two structural domains shown in Figure 15. As noted previously a group of Laramide plutons also follows this line. Potassium-argon dates on the plutons by Damon and Mauger(1966) are in the range of 53 to 73 million years in age. The southwest Arizona lineament is here considered to be the northwest-trending zone of weakness along which the collapse structure of Pima and Santa Cruz Counties formed (Figure 16). Like most lineaments this zone probably is an ancient deep-seated zone of weakness in the basement rocks that has influenced the younger structural development of the area.

Mayo(1958) recognizes one other major lineament that seems to have some influence upon the collapse structure. This he terms the Morenci belt. The Morenci belt extends in a northeasterly direction through southern Arizona and crosses the collapse structure near the Pima County-Pinal County line (Figure 15). This crossing is evident from the sharp right lateral offset in the boundary between the two structural domains, by a change in foliation attitudes, and by two northeast-striking faults.

Origin of Southern Arizona Basin and Range Structure

Wertz(1966) proposes that the Basin and Range province owes its structure to a modified anticlinorium produced by regional compression and subsequent stress relaxation. He states, p. 26:

> "Roughly oriented north-northwest at many places, the very irregular and complex, elongated blocks of outcrops in the Basin and Range province, apparently represent fragments of anticlinal folds belonging to a large anticlinorium. There may thus have occurred a subsequent release of the compressional stresses, resulting in tension faults along the outcrop blocks, together with a collapse of the adjacent synclinal blocks."

Evidence obtained by the present author rules out the formation of Basin and Range structure by regional compression. If the mechanism suggested by Wertz is correct then the individual ranges of southern Arizona should be characterized by relatively symmetrical structure, that is, they should be anticlines or domes. Instead the data in Figure 15 indicate that most of the ranges are faulted homoclines except for those lying on the line separating the two sides of the collapse structure. If folding under regional compression has taken place then fragments of the large folds should be readily apparent. Observation indicates that the dips in the ranges are similar over large areas so that large scale folding is ruled out.

Examination of the Arizona County Geologic Maps (Wilson, Moore, and O'Haire 1960) indicates that northwest-trending ranges and northwest strikes are dominant over much of the Basin and Range province of Arizona in rocks younger than Precambrian. Although no detailed study of areas other than Pima and Santa Cruz Counties has been attempted by the author, it seems likely that collapse similar to that suggested for southernmost Arizona may be responsible for attitudes of many northwest-striking fault blocks throughout the Basin and Range province of Arizona. Possibly the other northwest-trending lineaments recognized by Mayo have served as points of origin for additional collapse structures. More study is needed to determine if additional collapsed areas exist and to determine their ages.

The author proposes that the Basin and Range province of Arizona is basically composed of several collapse structures having northwest-trending axes that probably developed through the action of vertical uplift and a northeast direction of regional crustal extension.

In the section Mechansim for the Formation of the Structural Pattern, the possible relationship of the East Pacific rise to southern Arizona structure is mentioned. Lateral spreading of the crust away from the crest of the East Pacific rise is now fairly well established (Guilbert and Sumner 1968). Damon and Mauger (1966) point out the similarity of the Basin and Range province to the East Pacific rise in terms of topographic profile, structure, age, heat flow, and magmatic activity. They also agree with previous workers that the apparent passing of the East Pacific rise beneath the North American Continent on the west side of Mexico is reflected on the continent as the Basin and Range province. The East Pacific rise where it disappears at the edge of the continent has a north-northeast trend. If crustal spreading away from the crest of the rise is the cause of regional northeast extension in southern Arizona, then the trend of the rise must bend to the west upon passing beneath the continent. This change in trend is contrary to a recent interpretation of the northwest-striking San Andreas fault system of California as a transform fault (Wilson 1965) related to the East Pacific rise (Guilbert and Sumner 1968). Such a transform fault would strike perpendicular to the crest of the rise and require the rise to maintain a northeasterly strike. More information is necessary before this problem can be solved.

ECONOMIC GEOLOGY

The Oro Blanco mining district is probably best known for its gold and silver mineralization. The name of the district, literally "white gold" in Spanish, is derived from the light color of much of the native gold which is alloyed with a large percentage of silver. It is the gold and silver mineralization that has led to the development of dozens of small prospects, most of which have been totally unproductive. The precious metals have accounted for about one-half of the district production. The other half has been from base metals, principally lead and zinc, although some copper has been recovered as well. From 1873 to 1949 the total recorded production in the district is valued at about $10,498,000 (Wilson 1951). This has been recovered mainly from one property, the Montana mine.

With very few exceptions the precious metal showings have produced only small tonnages, but in some cases exceedingly high grades were encountered. It is these high grade showings that have made the Oro Blanco district the object of numerous mining promotional schemes.

Mining in the district was most active in the late 1870's and 1880's, and again in the 1930's. In recent years sporadic attempts have been made to operate several properties in the district, but these have met with little success.

History and Production

The following history of mining in the Oro Blanco district is quoted from Wilson(1951), pp. 41-42:

> "Gold deposits in the Oro Blanco district probably were worked by the early Spaniards. American locations were made in 1873 on the Oro Blanco vein. The prominent quartz outcrop now known as the Montana vein was located in the early seventies. Other locations followed soon afterward, and rich gold ore was ground in arrastras. The Ostrich mill, equipped with a roasting furnace to treat refractory sulfide ores, was built during the early eighties and operated by the Orion Company on ore from the Montana and Warsaw mines. This company obtained the Montana property and by 1884 had been reorganized as the Montana Company, controlled by Tombstone Mill and Mining Company.
>
> The Warsaw mill was built in 1882 and operated as a custom plant. In 1884 Esperanza Mines Company built a mill to treat ore from the Blain ledge.
>
> From 1887 to 1893, most of the mines were inactive.
>
> During 1894-96 mills operated at the Austerlitz, Yellow Jacket, Old Glory, Oro and Golden Eagle mines.
>
> At the Montana mine a 10-stamp mill, utilizing concentration and pan amalgamation methods to treat oxidized lead-gold-silver ores was built in 1891 but abandoned in 1893. The Montana claims were patented in 1907 by L. Zeckendorf.
>
> In 1903 amalgamation and cyanide mills were built to treat gold and silver ores from properties in the district.
>
> After 1904 little work was done until 1912 when the Austerlitz and Oro mines were reopened. A concentrator was built at the Austerlitz and operated for more than one year.
>
> In 1916 Goldfield Consolidated Mines Exploration Company obtained an option on the Montana property, completed a mill using flotation, and developed the mine to about the 250 level. It ceased operations in 1918, partly because of labor shortages and gave up its option.

> In 1926 Eagle-Picher Lead Company, as Montana Mines Operations, took an option on the Montana property. A mill of 250 tons daily capacity, equipped to use differential flotation methods, was completed in 1928. It was provided with an adequate water supply by means of a pipe line 15 miles long from Santa Cruz River. The mill was run intermittently until 1930. Subsequently its capacity was increased, and extensive production was maintained from late 1934 until May, 1940, by Eagle-Picher Mining and Smelting Company. The Montana Mine ranked as the largest producer of lead and zinc in Arizona for 1935 to 1939, inclusive, and third in output of silver for 1938.
>
> During recent years, Hugo Miller, of Nogales, has shipped from the Montana property lead-silver ore to the smelter at El Paso, Texas, and lead-zinc ore to the Eagle-Picher mill at Sahuarita, Arizona. Also, zinc-lead ore has been produced from the Choctaw and Lucky Shot mines; zinc-copper and copper ore from the Horn Gold claim; and gold and silver ore from several properties, as reported in the U. S. Minerals Yearbooks."

The above excerpt indicates that the first American location in the district was in 1873, but a private report on the Austerlitz mine by Schermehorn(1907) indicates that this property was first located in 1865. The original locater was killed by Indians but the property was relocated in 1869 which would still qualify it as the first location in the district.

The total recorded production from the district is as follows (Wilson 1951):

Silver,	1909-49	4,009,527 oz. valued at	$2,790,179
Gold,	1873-1949	98,142 oz.	2,623,069
Lead	1909-49	54,562,801 lb.	2,688,818
Zinc,	1917-49	38,256,989 lb.	2,061,017
Copper,	1909-49	3,152,630 lb.	334,942
			$10,498,025

Calculated at present metal prices (1969) the value of the metals produced from the district is about $25,500,000.

Table 1 is a list of mining properties in the district which have produced in the past or which are presently being developed.

Mineralization Types

Milton(1913) recognizes that the precious and base metals occur in three distinctively different types of deposits, quartz-sulfide veins, flat-dipping silicified "blankets", and mineralized breccia veins. Work by the present author indicates that most of the mineralized areas can be included in one of these three types so that Milton's classification has been retained here.

The quartz-sulfide veins are found throughout much of the Oro Blanco mining district, but the silicified zones and the mineralized breccia zones occur only in a small part of this area. The areas of occurrence of each of the three types are mutually exclusive except for some overlap between the breccia zones and the veins. The distribution of the three types of mineralization is shown in Figure 17.

Quartz-Sulfide Veins

The most abundant type of mineralization in the Oro Blanco district is the quartz-sulfide vein. The veins occur throughout the district although they are most abundant in two areas, near the Montana mine in the northeastern part of the district, and near the Warsaw mine in the south-central part. The veins have three major directions of strike, northwest, northeast, and north-northeast

Table 1. Mines and Prospects of the Oro Blanco Mining District

Name	Metals Produced	Mineralization Type
Alamo (placer)	gold	---------
Annie Laurie	uranium	quartz-sulfide vein
Apache	gold, silver	breccia vein
Austerlitz	gold, silver	silicified zone
Big Lode (Silver Top)	silver, lead, gold	quartz-sulfide vein
Black Diamond	lead, silver	quartz-sulfide vein
Brick	silver, gold	quartz-sulfide vein
Choctaw	zinc, lead, silver	quartz-sulfide vein
Dos Amigos	gold, silver	breccia vein
Grubstake	gold, silver	breccia vein
Hazel	gold, silver	quartz-sulfide vein
Hilltop	lead, zinc, silver(?)	quartz-sulfide vein
Holden	silver(?), gold	quartz-sulfide vein
Idaho	lead, zinc, silver	quartz-sulfide vein
Margarita (McDonald)	gold, silver	silicified zone
Missouri	copper, gold, silver	quartz-sulfide vein
Montana	lead, zinc, silver	quartz-sulfide
Nil Desperandum	copper, gold, lead	quartz-sulfide
Old Glory (Esperanza)	gold, silver	silicified zone
Oro	copper, gold, lead	quartz-sulfide vein
Oro Blanco	gold, silver	breccia vein

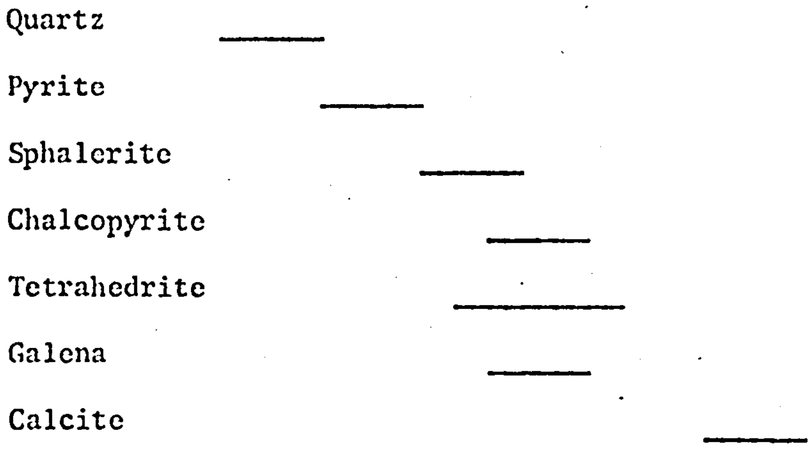
Table 1. Mines and Prospects of the Oro Blanco Mining District--Continued

Name	Metals Produced	Mineralization Type
Oro Fino	gold, silver	quartz-sulfide vein
Ostrich	gold, silver	quartz-sulfide vein
Ragnaroc	gold, silver	silicified zone
Reich	copper, silver	quartz-sulfide vein
Rubiana	gold, silver, lead, copper	quartz-sulfide vein
Skyline	gold, silver, lead	quartz-sulfide vein
Smuggler's Gulch	gold, silver	breccia vein
Sorrel Top	gold, silver	breccia vein
Tres Amigos	gold, silver	breccia vein
Union	silver, lead(?)	quartz-sulfide vein
Warsaw (Pittsburg)	silver, gold, copper	quartz-sulfide vein
Yellow Jacket	gold, silver	quartz-sulfide vein

parallel to the three major directions of faulting in the district. The Montana vein, the largest in the district, strikes nearly due west, but is really an extension of a northwest-striking fault zone. Dips of the veins are mostly more than 40°.

The characteristics of the veins vary considerably depending upon where they lie in the district. Near the Montana and Warsaw mines the veins generally consist of white quartz having a high percentage of pyrite, sphalerite, and galena, and smaller amounts of chalcopyrite and tetrahedrite. On the fringes of the district the color of the vein quartz is gray or bluish-gray and the percentage of sulfides is much less, generally not over one volume percent.

The following paragenesis is consistent with all of the veins from which polished sections have been made:



The younger sulfide minerals occur as fracture fillings and partial replacements of quartz and pyrite. Most polished sections show extensive intergrowth of chalcopyrite and galena. In addition chalcopyrite occurs as minute blebs in sphalerite, probably the result of exsolution. Tetrahedrite has been observed in only two sections but seems to replace both chalcopyrite and galena. Warren and Loofbourow(1932) noted that at least part of the tetrahedrite is older than the galena.

Many of the veins have undergone a certain amount of supergene enrichment. The principal minerals formed here are chalcocite, covellite, native silver, and the halides of silver.

Montana Mine. The Montana mine is the only property in the Oro Blanco district which has had a significant production over a period of several years. From 1928 to May 1940 the Eagle-Picher Lead Company milled a total of 773,197 tons of ore from the Montana mine averaging .06 oz/ton gold, 5.4 oz/ton in silver, 3.9% zinc, and 4.0% lead (private report). The ore contained values in copper as well, but no figures are available for this amount. Except for Eagle-Picher no one has produced a significant amount from this property.

The outcrop of the Montana vein was located in the early 1870's and gold was extracted from shallow workings. It was not until the advent of flotation that successful treatment of the complex sulfide ores was possible.

The Montana vein has been developed to a depth of 750 feet by a vertical shaft and nine levels that total an estimated 10,000 feet of workings. In addition a raise connects the surface with the 585 level which was used for back-filling of the stopes. Stoping has been from the tunnel level to the 660 level of the Montana vein and from the 300 to the 400 level of the Rough and Ready vein, a faulted segment of the Montana vein. In addition a small stope was opened at the eastern end of the Montana vein by Hugo Miller of Nogales after Eagle Picher operations ceased.

Much of the geological information discussed below is from work by Fowler(1938). The underground workings were not accessible to the author so that examination of the mineralization was limited to the surface. Figure 3 is a surface geologic map of the Montana mine area.

The Montana mine area is underlain principally by three blocks of Oro Blanco formation that are separated by faults. The central block is separated by a northeast fault from the northern block; and the southern block is separated from the central block by a west-northwest fault, the Montana vein. Both faults are normal faults having their northern sides downthrown. The southernmost block contains a part of the Ruby diorite sill which has been brought into contact with conglomerate of the central block at the Montana vein. The faulting has caused repetition of the southeastward dipping beds.

Mineralization followed the development of the two major faults and occurs principally as replacements of sheared and brecciated rock in the west-northwest fault and in the conglomerate on the hangingwall. The northeast fault apparently is not mineralized although a large vein has formed by replacement of a parallel shear slightly to the northwest, the Idaho vein.

A dike of Sidewinder quartz monzonite has intruded the Montana vein at the western end and offset a segment of the vein to form the Rough and Ready vein. Other Sidewinder dikes likewise have intruded the area. These strike nearly due west and dip about 45° north. A few steeply dipping Blue Ribbon andesite dikes have intruded all other units in the mine area. These have been offset slightly by late movement on the Montana vein and several minor faults.

The Montana vein is a zone of iron and manganese oxide-stained quartz that forms bold outcrops about 50 feet wide and several hundred feet long over a strike length of nearly 3,000 feet. Underground the vein ranges from mere stringers to over 40 feet in width. Fowler states that the vein is a replacement by quartz and sulfides of numerous shears which dip 40° to 90° north. Individual fractures making up the veins are arranged on echelon with offsets ahead and to the right indicative of a left-lateral strike-slip component of movement.

Fractures seem to be abundant and well-mineralized only in the conglomerate. Fowler feels that the diorite was more resistant to shearing because wide well-mineralized zones in the conglomerate pass into a few thin barren stringers in adjacent diorite.

The outcrop of the Rough and Ready vein is a strong contrast to that of the Montana vein. The Rough and Ready vein consists of a zone of thin quartz veinlets that seem to be barren of mineralization. According to Fowler this vein is barren to a depth of nearly 300 feet.

Orebodies in both the Montana and Rough and Ready veins rake about 45° westward. This angle of rake may be related to a mullion on the fault surface that developed prior to mineralization. Figure 3 indicates that the Montana vein lies on a nearly east-west part of a northwest-normal fault. Normal movement on this fault combined with a small left lateral strike-slip component of movement would produce a dilatent zone in the east-west part of the vein at the Montana mine. Movement along a mullion on the fault surface would form a dilatent zone which would rake westward at a moderate angle. The ore shoots were probably localized in such a mullion.

The mineralization consists of white quartz in which vugs have been filled with sulfide minerals. Considerable replacement of the quartz by sulfides has occurred as well. The sulfide minerals consist mainly of sphalerite, pyrite, and galena. Chalcopyrite and tetrahedrite are present but not abundant. The paragenetic sequence observed by the author is identical to that shown for the quartz-sulfide vein type discussed above. In some places calcite occurs as a late mineral that has cemented brecciated ore fragments. According to Warren and Loofbourow(1932) the precious metal values are in tetrahedrite nearly to the exclusion of the other minerals. They find that galena which contains silver also contains minute inclusions of tetrahedrite that are argentiferous. They analyzed samples of pyrite, sphalerite, and chalcopyrite finding that none of these contain appreciable precious metals.

The Montana oreshoot extends from the tunnel level to the 550 level, reaches a maximum length of 1,000 feet and averages 20 feet in width. The Rough and Ready oreshoot is considerably smaller extending from the 200 to the 400 levels and having a maximum length of 800 feet. The Rough and Ready vein is terminated at the 400 level by a Sidewinder quartz monzonite dike, but the Montana vein continues beyond the bottom of the workings at the 750 level. The Montana vein is virtually barren of sulfides below the 550 level but very wide even at the 660 level. A geologic map of the 750 level supplied to the author by Eagle-Picher Industries, Inc., indicates that the quartz veining ceases at this level at least in the eastern end of the vein where the workings were placed. Although no workings exist below the 660 level at the western end of the Montana vein possibly the oreshoot is present here owing to the westerly rake. The failure to find mineralization on the 750 level may have been due to passing out through the southeastern edge of the mineralized lense. It is likely that Eagle-Picher explored this possibility of a downward extension of ore by drilling beneath the western end of the workings even though a longitudinal section of the mine (Fowler 1938) showing drill holes that intersect the vein indicates no holes in this region.

Choctaw Mine. The Choctaw mine was first worked in 1895 by Dr. Noon who also owned the Austerlitz mine, discussed below. The vein has been prospected with a 200 foot inclined shaft and some lateral work on two levels, the 15 foot level and the 160 foot level. In addition, a 100 foot crosscut tunnel connects the 15 foot level with a portal. Early production is unknown and probably small. Ninety tons was shipped in the 1940's, a stockpile which accumulated from assessment work. The mineralization is in a northeast-striking, southeast-dipping group of quartz veins that intersect each other at very small angles. The veins dip from 31 to 60 degrees southeast. The wall rocks consist of the conglomerate member of the Oro

Blanco formation, which is underlain by Cobre Ridge tuff in depositional contact. The bedding in the conglomerate dips at moderate angles toward the southwest. The conglomerate is only about 200 feet in thickness and is overlain by black and green siltstone of the sandstone and siltstone member.

The veins have a 265 foot strike length and lie only within the conglomerate. No mineralization passes into the overlying or underlying rocks although a few barren quartz stringers have been found having the same strike several hundred feet to the northeast in the Cobre Ridge tuff. At the surface the vein has a maximum width of 1-1/2 feet; at a depth of 75 feet it swells to 4 feet; and at 200 feet, the bottom of the shaft, pinches to 17 inches (private report).

The mineralization consists of white vein quartz having a large percentage of disseminated sphalerite and galena, and a small amount of pyrite. Argentite has been reported (private report) but the author has not seen any. The results of a sampling program conducted here in the 1940's yield averages of .01 oz/ton gold, 4.1 oz/ton in silver, 7.5 percent lead and 7.6 percent zinc. Copper values are present, but low, and are due to small exsolved chalcopyrite blebs in the sphalerite.

The principal control on mineralization seems to be the favorable host rock, the conglomerate, which probably fractured more readily than the other rock types.

<u>Brick Mine.</u> The Brick mine lies about 1 mile west of the Montana mine on the same fault zone. The property is credited with a

production of 3242.5 tons of ore averaging .098 oz/ton in gold and 18.34 oz/ton in silver (private report). The workings are flooded at the time of this investigation but the development is said to consist of short drifts on 5 levels to a maximum depth of 170 feet. Development is limited to a distance of about 180 feet along strike.

The Brick mine is on a mineralized portion of a large displacement northwest fault. The footwall of the vein is the welded tuff member of the Cobre Ridge tuff and the hangingwall is Oro Blanco formation. Both units dip southwards, opposite to the direction of dip of the fault.

The outcrop of the Brick vein consists of a six foot wide zone of brecciated conglomerate, quartz latite tuff, and Ruby diorite that has been cemented firstly by quartz and small amounts of sulfides, and secondly by calcite. The vein strikes N 70° W and dips about 55° northeast. As exposed at the surface the vein is very vuggy. Only a distance of about 300 feet along strike has been mineralized. A few feet northwest of the workings the quartz-cemented breccia grades into a very gougey fault zone about 10 feet in width which is barren of mineralization. About 200 feet southeast of the workings the vein becomes a thin zone of barren quartz stringers. Underground the vein is said to be mostly 4 to 12 feet in width, but rarely reaches 18 feet.

The mineralization consists of white brecciated quartz and a small percentage of fine-grained galena, pyrite, sphalerite, chalcopyrite, and tetrahedrite. In addition a few small wires and sheets of native silver were found here by the author. Most of the vein matter has been brecciated and recemented by large amounts of calcite.

The mineralization is concentrated in a small oreshoot that rakes about 60° west, similar to the oreshoots at the Montana mine. This oreshoot may owe its origin to a mullion on the fault surface, but it is also possible that it has been localized by the intersection of the northwest fault with a northeast cross fault in the footwall of the vein (Figure 3).

Warsaw Mine and Reich Prospect. The Warsaw mine and Reich prospect lie in the south central part of the Oro Blanco district in a zone of northeast quartz-sulfide veins cutting Ruby diorite.

The Warsaw vein was located in the late 1800's. It produced gold and silver and probably copper from the oxidized surface material. Attempts to treat the underlying sulfide ores were unsuccessful. No production figures are available for this property. Some work has been done here in recent years as evidenced by a fresh orepile having good silver and copper values.

The Reich prospect lies southeast of the Warsaw mine on the same mineralized zone. The origin of the early development work here is unknown, but presently an attempt is being made to produce copper and silver from the property. The mineralization is developed by a shaft of unknown depth, several hundred feet of drifts on an adit level, and three winzes about 40 feet in depth. A cut has recently been opened to expose the southwestern end of the vein.

Although the mineralogy is similar to that of the Montana vein, the Warsaw vein contrasts sharply with it in other characteristics. The Warsaw vein is a northeast striking, steeply dipping vein in Ruby diorite. The vein is found mostly in the diorite and stops at the contact with the Oro Blanco formation on the northeast. It seems to have occupied a tension fissure that formed during the emplacement of the diorite sill. It consists of a zone 5 feet in width of white quartz cut by a large number of pyritic stringers, and containing disseminated sphalerite, galena, and chalcopyrite. Tetrahedrite may be here but has not been observed by the author. Supergene minerals include chalcocite, covellite, native silver, and embolite. Only one sample was taken here which is from a sorted ore pile. It assayed 25.5 oz/ton in silver and .014 oz/ton in gold. This vein differs from the Montana vein in the high content of pyrite. The Montana vein averages about 4 percent of pyrite, whereas the Warsaw vein generally contains 25 percent or more. Galena is less abundant here, sphalerite about the same, and chalcopyrite more abundant.

The Reich prospect is likewise on a northeast vein and seems to be a faulted part of the Warsaw vein that has been offset by late movements on a northwest fault. At the Reich prospect the vein cuts the welded tuff member of the Cobre Ridge tuff and Ruby diorite, but is cut by three large rhyolite dikes. The southwest end of the vein has been cut off by a northwest fault that is now occupied by a rhyolite dike. The hypogene mineralization is confined to a zone of quartz stringers and a quartz vein which pinches and swells from 0 to about 10 feet in width. The major sulfide mineral is pyrite which comprises over 25 volume percent of the vein. The next most abundant sulfide is sphalerite followed closely by chalcopyrite. Galena is very sparse and tetrahedrite has not been observed at all by the author. Judging from the silver present here some tetrahedrite probably occurs. Gold in the vein is low, rarely more than .02 oz/ton.

The principal metals for which this property is being exploited are copper and silver. Weathering of the pyritic vein has produced some secondarily enriched copper in the vein and a fairly extensive area of exotic copper mineralization in the wall rocks, especially in the diorite. According to Edward Reich (oral communication) much of the vein assays about 6 oz/ton in silver and from 2 to 4 percent copper. These values are probably for the supergene enriched material, for visual estimates of primary vein matter suggest about a one percent copper assay.

Yellow Jacket Mine. The Yellow Jacket mine is one of the earliest locations in the Oro Blanco district. The property is credited with a production of $243,134 in gold and silver that was recovered from 13,200 tons of ore (private report). The ore body was virtually worked out before 1900. The workings now are caved but the development is said to consist of a main shaft 250 feet in depth that serves four levels involving about 1,200 feet of drifts and short cross cuts. A second shaft 62 feet in depth connects into the upper level. In addition a 200 foot crosscut has been driven northwest of the main shaft.

The Yellow Jacket vein lies in a major northwest fault zone that dips steeply northeast. The vein consists of a shear zone 10 to 30 feet in width containing blocks of dark bluish gray quartz. Rhyolite dikes have intruded the vein and the adjacent wall rocks. The wall rock here consists entirely of the welded tuff member of the Cobre Ridge tuff.

Although all of the vein matter that was observed by the author is oxidized to iron oxides and a small amount of chrysocolla, it seems as though the percentage of original sulfides in the vein was very low, probably not over one percent.

The Yellow Jacket vein contains a fairly large amount of gold compared to its silver values. The silver to gold ratio for this vein is about 9 to 1 whereas at the Montana vein it is about 90 to 1.

The reason for localization of the ore body is not known because of the lack of subsurface data and poor surface exposures.

Ostrich Mine (Bartlett mine). The Ostrich mine is developed on the same fault zone that contains the Yellow Jacket mine but lies about 1/2 mile to the southeast. The production from this property is unknown, but according to production figures given by Wilson and others(1934), p. 188, the property was active during the period 1873 to 1886, but has had no recorded production since this time. The workings are now caved but are said to consist of a 60 foot vertical shaft, a hundred foot incline shaft, and about 100 feet of drifts connecting the two shafts. According to a private report on the property a small amount of 3 oz/ton gold ore was shipped from the bottom of the inclined shaft from a vein 7-1/2 feet in width.

The geology of the Ostrich vein is very similar to that of the Yellow Jacket vein. The Ostrich vein consists of slightly iron and copper-stained bluish gray quartz fragments scattered throughout a zone of badly sheared and clay-altered Cobre Ridge tuff that is about 20 feet in width. The vein strikes N 33° W and dips about 50 degrees northeast. It is slightly mineralized at several points between the Yellow Jacket and Ostrich mines and in several areas of the same vein southeast of the Ostrich.

On the hillside northeast of the main vein are several areas where thin northwest-striking quartz stringers have been prospected. These small stringers as well as the main vein are locally very high in grade, sometimes assaying 4 to 6 oz/ton in gold (private report) and about an equal amount in silver. The values are very erratic, however, so that general grade of the veins is rather low. The average of three samples taken by the author at various points on the main vein within a few feet of the surface is 0.225 oz/ton in gold and .84 oz/ton in silver. Copper and zinc values are surprisingly high for this vein, about .45 and .25 percent respectively. Lead values are very low, less than .1 percent, the limit of detection of the analytical method. As at the Yellow Jacket mine, silver to gold ratios are low, averaging about 2.8 to 1 based on 13 assays from various parts of the vein. The specific controls on ore localization are unknown here as at the Yellow Jacket mine.

Miscellaneous Examples. Other examples of quartz-sulfide veins include the Oro and Nil Desperandum mines on northwest veins which have values in gold, copper and lead; the Choctaw, Idaho, and Hilltop mines, northeast veins having values in lead, zinc, and silver; and manganiferous north-northeast veins southeast of the Warsaw mine having values in lead, silver, and some zinc. Many other examples of the quartz-sulfide vein type of mineralization occur in the Oro Blanco district, but the main characteristics are covered in the veins discussed above. The major metals present in the veins are shown in Figure 17. The veins are classed according to the dominant metals present and according to whether or not they contain significant amounts of gold or silver.

The ore controls for most of the miscellaneous veins are not known in detail except for the Oro mine where the intersection of northwest faults and northeast cross faults may have localized oreshoots (private report).

Summary. In general the quartz-sulfide veins are very similar throughout the district although the particular metal values and ratios vary considerably from vein to vein (see District Zoning for discussion). The veins have three dominant strikes, northeast, northwest, and north-northeast, parallel to the three major directions of faulting. Most of them dip at moderate to steep angles. Polished sections examined from several veins in various parts of the district indicate that the paragenesis of all examined veins is the same.

Ore controls in the district seem to be of three types, two of which are interrelated:

1) zones of dilation such as rolls on fault surfaces and tension fractures.
2) intersections of northwest faults and northeast faults.
3) host rock favorability, probably related to ease of brecciation, as shown by the Oro Blanco Conglomerate member.

Some of the veins, such as the Montana and Warsaw vein, are moderately persistent along strike; others such as the Brick and Choctaw have very limited strike persistency. Mining experience indicates that the depth persistency of the veins is poor. Even the largest vein in the district, the Montana vein, is mineralized only over a vertical range of 800 feet including the leached outcrop. Most of the veins reached uneconomic mineralization within 350 feet of the surface, and many within 200 feet of the surface.

Secondary enrichment has contributed considerably to the value of the veins near the surface. The metals involved here are principally silver, gold, and copper. This accounts well for the early exploitation of many veins in the district for gold and silver from shallow workings even though the protore in many of the same veins is nearly devoid of precious metals.

The precious metal veins, typified by the Yellow Jacket and the Ostrich, are even less persistent than the base metal veins. The Yellow Jacket orebody, the largest in the district of this type, yielded only a little more than 13,000 tons. Most others in the district have produced considerably less although they commonly contain small bodies of very high grade ore. For example the Hazel claim northwest of the Yellow Jacket mine produced a total of .183 tons of ore from an 8 inch wide quartz vein that averaged 3.85 oz/ton in gold and 1.7 oz/ton in silver (Fred Noon, oral communication).

Although the grades of some of the precious metal bearing veins are fairly good, they are too small to be worked at a profit by anyone even though the mineralogy is simple.

Silicified Zones

The silicified zones are the second most productive type of mineralization in the Oro Blanco mining district. These have produced only gold and silver. Only two areas of the district contain silicified zones, both of which lie in the north-central part of the district (Figures 3 and 17).

The silicified zones consist of northwest-striking, gently northeast-dipping zones of white quartz veinlets and stringers that have replaced and filled fractures in the host rock. The host for all of the silicified zones is Cobre Ridge tuff which has been sericitized in and adjacent to the silicified zones. In many of these zones the quartz veinlets contain a large percentage of pyrite and exceedingly small amounts of chalcopyrite, sphalerite, galena, and tetrahedrite. The precious metal values occur only in the pyritic areas, but no quantitative relationship between precious metal content and pyrite content has been demonstrated. The sulfides other than pyrite are too sparsely distributed to permit determination of the paragenesis for this type of mineralization.

The relative ages of the quartz-sulfide veins and the silicified zones are unknown, for at no place has one been observed cutting the other. The same is true for the silicified zones and the other major type of mineralization, the breccia veins. The resemblance of the silicified zones to the usual steeply-dipping pyritic quartz vein suggests that the zones are tilted veins that formed before faulting and rotation of the Mesozoic rocks, but little evidence exists for this. The large displacement northwest fault that lies between contiguous portions of silicified rock (Figure 3) such as near the Austerlitz mine and one half mile south of the Rubiana prospect shows that the mineralization is younger than the faulting and therefore younger than the tilting of the host rock. The silicified zones are everywhere cut by dikes of Sidewinder quartz monzonite so that these zones are probably about the same age as the quartz-sulfide veins. Three principal mines have been developed on this type of mineralization, the Margarita, Austerlitz, and Old Glory mines. In addition numerous prospects have exposed most of the pyritic areas in the outcropping silicified zones.

Austerlitz Mine. Development work at the Austerlitz mine consists of about 2,000 feet of lateral work on two levels and three shafts, two of which have been refilled. The remaining shaft is said to be 130 feet in depth. Other work includes numerous small open cuts and trenches and a small adit in a silicified zone on the hill southeast of the main workings.

Prior to the discovery of a blind oreshoot in 1912 most of the developments were on two steeply dipping northeast veins and on small high grade showings in exposed silicified zones.

Most of the production has been from the blind orebody that was discovered in 1912. This produced about $96,000 in a two year period from what is now called the Crawford stope.

Two carloads of oxidized ore from the Barckley stope were shipped in the 1940's and a few tons of bulk samples were shipped from this property in more recent years for tests as a source of smelter flux.

The geology of the Austerlitz mine area has been studied in detail in order to determine the controls on mineralization. Another purpose of studying the Austerlitz mine was to determine the relationship of the Sidewinder dikes to the mineralization.

The geology of the mine surface and underground workings is shown in Figures 18 and 19. The dominant rock type in the area is the welded tuff member of the Cobre Ridge tuff. This is overlain by and in fault contact with a small thickness of Oro Blanco formation. The mine area has been complexly intruded by several thick dikes of Sidewinder quartz monzonite along pre-existing fractures and fault zones.

Mineralization at the Austerlitz mine is of two types, northeast quartz-sulfide veins and flat-dipping northwest-striking silicified zones. Neither type has been observed cutting the other. Judging from mineralogical similarities they may be of the same age.

The silicified zones have been most productive, but the veins are commonly higher in grade. This higher grade may be due to supergene enrichment that has not greatly affected the silicified zones.

The flat-dipping silicified zones are lenslike bodies of strongly silicified Cobre Ridge tuff that consist of a myriad of thin white quartz veinlets and stringers having a widely variable amount of disseminated pyrite, and small amounts of chalcopyrite and tetrahedrite. The precious metal values range from a mere trace to over 1 oz/ton in gold and 30 oz/ton in silver. Fifty-five samples taken in the Crawford stope (on the principal productive silicified zone) yield averages of .083 oz/ton in gold and 6.04 oz/ton in silver (Gregory 1935). The Crawford orebody consists of a northwest-striking silicified zone that dips at small angles to the northeast, ranging from 6° to 31°. Thicknesses of the ore zone range from zero to about 12 feet and average about 6-1/2 feet. The ore body is generally surrounded by Sidewinder quartz monzonite which is intrusive into the mineralization. It is an inclusion that is totally enclosed in Sidewinder quartz monzonite. At several places the mineralized zone pinches out to become a thin black parting line in a Sidewinder dike. This parting has been observed everyplace where the mineralization pinches out suggesting that the Crawford orebody has been caught between two separate Sidewinder dikes, one on the footwall and one on the hanging wall.

Other pieces of the same silicified zone that probably are caught between Sidewinder dikes are exposed just northwest of the

Crawford portal (Figure 18) and at the Ragnaroc mine, farther to the northwest. The hanging wall dike has been eroded to expose these segments of the zone but is intact over the Crawford orebody so that the orebody nowhere crops out.

Silicified zones similar to the Crawford orebody, but smaller, are exposed on the hilltop about 1,000 feet south of the main workings. Here a block of Cobre Ridge tuff, part of which is silicified, is surrounded by Sidewinder quartz monzonite. To the south is a wide exposure of silicified Cobre Ridge tuff that is still connected to the main body of the tuff (Figure 3).

The spatial relationship of the Sidewinder quartz monzonite to the silicified zones is merely structural and not a genetic association. The quartz monzonite is clearly younger than the mineralization. It seems that the same structures that localized the mineralization also served as the loci for intrusion of the Sidewinder dikes, a relationship that exists at the Montana mine in the quartz-sulfide vein type, and at the Tres Amigos mine in the breccia vein type (to be discussed later).

At the Austerlitz mine, evidence for the structures that localized mineralization is sparse, consisting only of a crackling and local brecciation of the Cobre Ridge tuff that is visible near the fringes of the silicified zones. Generally within the silicified zones the replacement of the host rock by quartz has been so extensive that no breccia fragments are recognizable.

Faults in the mine area have somewhat offset the mineralization and the quartz monzonite dikes. These strike about N 65° E and commonly dip from 40 to 80° northwards. The amount of displacement on these is unknown, but one which cuts the Crawford orebody has offset it only a couple of feet. The large fault zone that is parallel to the east end of the Barckley tunnel (Figure 19) probably has considerably more displacement.

Old Glory Mine (Esperanza Mine or Blain Ledge). The Old Glory mine has been developed on the southernmost exposures of the silicified zones. The mineralized zone forms a flat-dipping cap of a large hill so that much of the development has been done by surface stripping and a shallow open pit. In addition there is an underground stope measuring about 50 by 100 feet by 10 feet high. Two haulage tunnels have been driven under the workings from opposite sides of the hill that were fed by a chute from the open pit. In 1884 a mill was constructed on the property at the base of the hill along Old Glory Canyon. All haulage of ore was downhill. A private report on this property dated 1900 states that the reserves were 200,000 tons having an average value of $5.00/ton. In view of the downhill haulage and surface stripping it may have been possible to mine this at a profit, although Blake(1899) states that the operation of this property would be very marginal. Estimates by the author indicate that about 17,000 tons of mineralized rock have been removed from all accessible workings. Judging from the size of the dumps remaining on the property certainly not over 3/4 of this amount has been milled. This would yield an estimated production of about $63,000 from the property. The actual production is unknown to the author.

The Old Glory mine (Figure 20) is underlain by the welded tuff member of the Cobre Ridge tuff. The mineralized zone forms the cap of a steep-sided northwest elongated hill. The zone strikes N 30 to 60° W and dips 0 to 30° northeast. It dips more gently than the northeast side of the hill so that the downdip extension of the mineralization has been removed by erosion. Several hundred feet farther to the northeast the continuation of the mineralized zone crops out again.

The mineralization consists of a massive quartz core 10 to 30 feet in thickness bordered on the hangingwall and footwall by zones of flat-dipping quartz veinlets to form a silicified body that has a total thickness of about 50 feet.

Most of the development work is confined to the 4 to 12 foot thick pyritic quartz veinlet zone on the hangingwall. This area has been strongly oxidized so only rarely are any relict pyrite grains visible. In the subsurface stope small amounts of chalcanthite have been observed, but in general the only visible minerals are quartz and iron oxides.

The core of the mineralized body consists of pure massive white quartz, although locally a few pieces of pyrite have been observed.

The quartz stringers and veinlets of the footwall resemble those of the hangingwall but generally contain very little pyrite.

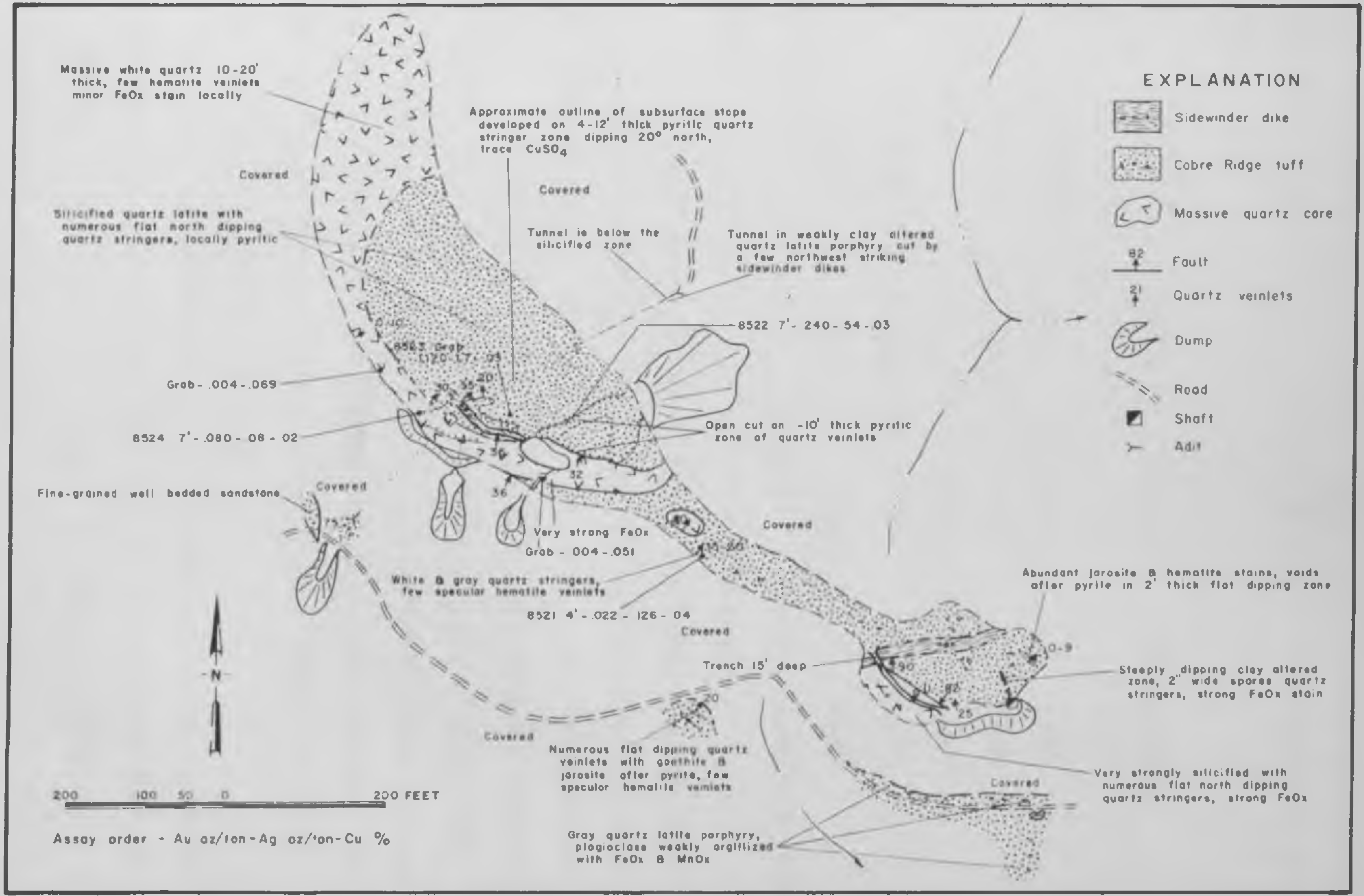


Figure 20. Geologic Sketch Map, Old Glory Mine

A few samples were taken at the Old Glory property from the three major divisions of the mineralized zone. The results are given below:

Location	Width	Gold oz/ton	Silver oz/ton
Hangingwall	7 feet	0.240	0.54
Hangingwall	grab	1.120	1.70
Core	7 feet	0.080	0.080
Core	grab	0.004	0.051
Footwall	4 feet	0.020	0.126
Footwall	grab	0.004	0.069

The sampling indicates that the best grade of mineralization is confined to the hangingwall zone, the most pyritic part.

Northwest faults of small displacement have slightly offset the silicified zone (Figure 20). They are downthrown on the southwest side and cause a repetition of the outcrops of the silicified zones. These faults probably have displaced the down-dip extension of the Old Glory zone to form the numerous patches of silicified Cobre Ridge tuff that crop out north of the Old Glory mine and near the Margarita mine. One of these faults has a throw of about 200 feet and separates two exposures of silicified rock on the north side of Old Glory Canyon (Figure 3).

After the offsetting of the silicified zones by the northwest faults the Old Glory mine was intruded by two small dikes of Sidewinder quartz monzonite. One of these has intruded parallel to the mineralized zone. This is exposed in the open pit in the top of the ridge. The other dike cuts the mineralization obliquely, striking northeast and dipping nearly vertically. These dikes are very small compared to those at the Austerlitz mine, neither is over 20 feet in thickness. Localization of the mineralization by a fracture zone is even less obvious at the Old Glory mine than at the Austerlitz mine. Little evidence of brecciation or pre-mineralization faulting has been observed at or near the Old Glory property. Here the quartz veinlets have very diffuse contacts with the host rock, suggesting active replacement of the host. The veinlets are nevertheless parallel to one another and cut the foliation of the host rock at a large angle suggesting some sort of fracture control rather than replacement parallel to foliation planes.

Margarita Mine (McDonald prospect). Most of the description of the Margarita mine comes from Wilson and others(1934). The author has examined this property only in a very general way.

In the 1890's the property was prospected by about 1,200 feet of tunnels and shallow workings from which a small amount of gold was produced. From late 1931 through at least 1934 Margarita Gold Mines Company developed the property and produced gold bullion from a 50 ton/day cyanide mill. Production from this property is unknown. Two areas of silicified Cobre Ridge tuff have been opened by surface cuts. One of these near the mill site is about 200 feet by 100 feet by 80 feet in depth. This zone consists of numerous quartz veinlets and stringers in sericitized Cobre Ridge tuff that have abundant pseudomorphs of limonite after pyrite. The areas containing the most abundant pseudomorphs seem to be of highest grade as mentioned by Wilson and others(1934). This has been substantiated by the author from panned samples. Wilson further states that the mineralized area contains a large tonnage averaging .3 oz/ton in gold and .5 oz/ton in silver. About 1,000 feet to the east of these workings is another silicified zone that has been opened by a cut about 200 feet long by 30 feet wide by 10 feet deep. This has a winze extending to a depth of 50 feet at the northwest end. The cut is mainly in strongly iron stained, silicified, and sericitized Cobre Ridge tuff and a thin shear zone that dips gently northwards. In the winze the mineralization consists of white quartz and a large percentage of pyrite. It is not known whether any precious metals have been produced here or even if the zone contains significant amounts of gold or silver. Panning of the oxidized material from the cut reveals no gold whatsoever, but it might be too fine-grained to recover by panning. Such fine-grained gold has been found in the upper workings at the Austerlitz mine where material apparently barren of gold in the pan, assays 0.385 oz/ton.

Discussion and Summary. The flat-dipping silicified zones lie principally in two areas in the district. The one area near the Austerlitz mine contains several separate bodies of silicified Cobre Ridge tuff most of which are separated from one another by Sidewinder quartz monzonite. The many mineralized zones here probably represent fragments of one silicified zone that has been broken up and displaced by dikes of Sidewinder quartz monzonite and small displacement faults.

Likewise the silicified zones near the Margarita and the Old Glory mines probably are fragments of a single mineralized zone.

The significant points concerning the silicified zones are as follows:

1) They have been of economic significance only because of their precious metal content. Base metal minerals are very sparse.
2) They contain a large percentage of pyrite with which the precious metals are associated, but not all pyritic areas contain precious metals. Quartz free from pyrite is nearly barren of gold or silver.
3) The spatial association of the silicified zones with the Sidewinder quartz monzonite is a structural association, not a genetic one. The dikes are distinctly younger than the mineralization.
4) Although the age relationship between the quartz-sulfide veins and the silicified zones is uncertain, it is likely that they are nearly the same age.

Breccia Veins

The third major type of mineralization in the Oro Blanco district is that of mineralized breccia veins. These lie in a fairly well-defined area southeast of the Old Glory mine (Figure 17). They are northwest and north-northwest striking, steeply-dipping tabular zones of brecciated and sheared country rock. These range widely in width from an inch or two to about 35 feet. Even within a given brecciated zone the width varies considerably. The breccia veins are composed of brecciated Cobre Ridge tuff or Oro Blanco formation that is commonly bounded by smooth planar walls (Figure 21). Rarely is any gradation from slightly fractured country rock to the breccia observed, instead there is a sharp planar boundary. Some veins such as those at the Oro Blanco and Tres Amigos mines have been sheared. These contain gougey shear zones that form the walls and cut through the breccia.

The mineralization which is visible with a hand lens consists of a very small amount of clear or yellow finely crystalline quartz that cements the breccia fragments and a very small amount of iron and manganese oxides. The fragments and the wall rocks adjacent to the breccia have been bleached white through alteration of the feldspars to a white clay, probably kaolinite. No sulfide minerals have been found in any of the veins because development has not penetrated below the zone of oxidation. The small amount of iron oxide stain and the lack of cellular structure indicate that the percentage of original sulfides was very low, probably much less than 1 percent.

The mineralization of economic significance in these zones consists mostly of native gold particles smaller than 20 mesh grain size, and mostly of about 100 mesh grain size. Panning of material from many of these zones has revealed a small amount of native silver, although this is far less abundant than the gold particles. The silver content, as determined by assay, is about 10 times the content of gold so that much of the silver is probably present as either

Figure 21. Breccia Vein

Vein trends vertically across photograph. Note sharp contact between breccia zone and walls and the bleaching in the breccia zone.

fine-grained halides or tied up in the iron oxides as argentojarosite or as silver that has been co-precipitated with the iron or manganese oxides.

Assaying of the veins reveals that many contain about 0.1 to 0.2 oz/ton in gold and about 1 oz/ton in silver. A crude calibration of the author's gold pan, based upon counting colors in assayed material, was used to gage the uniformity of distribution of the gold in the breccia zones. Panning has revealed that all of the breccia veins sampled are gold-bearing but those in the central and southeastern parts of the group are of the highest grade. In individual zones the gold seems to be most abundant in concentrations of iron and manganese oxides. The width of the vein seems to have little effect on the overall grade of the vein, narrow parts are mineralized to just about the same degree as the wide parts. In some cases the footwall edge of the vein contains higher values than the rest of the vein such as found by Keyes(1923) at the Tres Amigos mine. Here a 1 to 3 inch clay selvage on the footwall is said to run 3.7 to 9 oz/ton whereas the full width of the breccia zone in the stopes runs .6 to 1 oz/ton. The breccia zones seem to have been formed in part by intrusion of fluidized country rock fragments into joints as was discussed in the section titled Northwest Faults. The displacement on the zones that have been sheared seems to be small so that they may be equivalent in age to the northwest faults that slightly offset the silicified zones. The breccia zones definitely cut the quartz-sulfide veins making them the youngest type of mineralization in the Oro Blanco district.

Tres Amigos Mine. The Tres Amigos mine lies in the southeastern part of the group of breccia zones. The production from the property is unknown. Wilson and other(1934) list the district production for the period 1894 to 1904 as $337,500 from several properties including the Tres Amigos. The major development on the property was during this time period although a small amount was done later in the 1930's. A crude estimate suggests that the maximum tonnage produced from the accessible stopes is about 10,000 tons. Keyes(1923) states that the average grade of ore in the stopes was $12 to $20/ton so that a conservative estimate of the total production is about $120,000. The mineralized zone has been opened by a 2,000 foot adit, four winzes said to be 100 feet in depth, and three stopes that are known to the author. Blake(1899) states that a few lots of high grade ore valued at $500/ton were shipped from the southeastern end of the mineralized zone. The Tres Amigos mineralized zone strikes about N 35° W and dips very steeply to the northeast. On the surface the vein is traceable over a strike length of about 2,000 feet. Most mining of the zone has been on the southeastern end where it locally reaches widths up to 35 feet. The average width, however, is about 4 or 5 feet. About 500 feet from the southeastern end, the breccia has been intruded by a thick dike of Sidewinder quartz monzonite that follows the vein.

All of the major stopes are within 50 feet of the surface even though the vein cuts through a steep hill having a relief of about 200 feet. According to Keyes(1923) the mineralized breccia at the adit level averages about $6 to $12/ton whereas the stopes that are nearer to the surface average $12 to $20/ton. He further states that the vein is nearly barren at the watertable. Such large vertical variations in the grade may be related to residual enrichment of the gold near the surface and downward physical transportation of the fine-grained gold, or possibly to the primary deposition of the gold in an epithermal environment.

Other Breccia Veins. Other small mines that have been developed upon the mineralized breccia veins include the Oro Blanco, Dos Amigos, Smuggler's Gulch, Monarch, Sorrel Top, Grubstake, and Apache mines. In addition a large number of prospects having up to a few hundred feet of workings have been developed on many other smaller veins. The production from these is unknown, but probably is small with the possible exception of the Oro Blanco mine.

Summary. The breccia zones are the youngest type of mineralization in the district. They are present only in a small part of the district, the south-central part, as northwest-striking, steeply-dipping tabular zones. These mineralized features consist of brecciated country rock that may have intruded as a fluidized mass into pre-existing fissures. Mineralization is limited to small amounts of gold and silver. Base metal minerals have not been observed in any of the breccia zones. The silver to gold ratio for these is about 10 to 1.

Miscellaneous Mineralization

Three types of mineralization which occur in the district do not fit into the above groups. These are barren of metallic mineralization. The oldest of the three consists of quartz and tourmaline veins which cut the Warsaw quartz monzonite and Cobre Ridge tuff. These veins formed after the first period of movement on the north-northeast faults, but before the deposition of the Oro Blanco formation.

The second type of barren mineralization consists of strongly banded and crustified vuggy quartz veins. These are of white and amethystine quartz, and many siliceous boxworks after calcite. These occur only in the north-northeast faults which cut the Warsaw quartz monzonite just west of the Warsaw Canyon road. The age of this mineralization is unknown, but the banded and crustified texture suggests a fairly near surface environment of deposition compared to the quartz-tourmaline veins. It is probably much younger than the quartz-tourmaline veins, possibly Tertiary.

Calcite-filled veins comprise the third type of barren mineralization. These commonly have formed where late displacements along quartz-sulfide veins have caused extensive brecciation such as at the Brick mine. These veins cut the Sidewinder and Blue Ribbon dikes, so they must be Tertiary in age.

Placers

Placers have been formed from the erosion of the various gold-bearing deposits in the district. Placering has been attempted in at least three areas, in and near Alamo Wash, at the junction of Warsaw Canyon and California gulch, and in the area near the Black Diamond prospect east of Bartlett Mountain. Attempts to work them on a large scale have not been successful. From 1896 to 1942 the district has been credited with a production of about 840 ounces of gold from placers (Wilson 1961).

Alteration

Large areas of pervasive hydrothermal alteration characteristic of mineralized districts are lacking at Oro Blanco. Altered halos surround most of the quartz-sulfide veins and silicified zones, but rarely extend more than a few feet away from them.

Several propylitically altered patches have been observed in various parts of the district which cover areas up to about 20 acres in Oro Blanco Conglomerate on the hangingwall of Ruby diorite bodies. The alteration consists of partial sericitization of the plagioclase, addition of about 1 volume percent of pyrite, chloritization of mafic minerals, and some argillization that is probably supergene. These areas are best exposed near the Grubstake mine in the south-central part of the district, and about 1,000 feet north of the Brick mine. The altered area near the Grubstake mine is strongly anomalous in silver, but this seems to be related to many northeast quartz veinlets that cut the altered area. The alteration seems to be related to the emplacement of the diorite, whereas the silver was probably introduced at a later time.

Alteration in and adjacent to the quartz-sulfide veins and the silicified zones consists of pervasive sericitization which yields outwards over a few inches or a few feet to argillized iron-stained wall rock. Much of the argillization here is probably supergene.

The alteration associated with the breccia veins is the least extensive of all types of mineralization. Generally this consists of a slight bleaching of the breccia fragments and the wall rocks for an inch or two on either side of the vein, although locally considerable white clay, probably kaolin, has been produced.

District Zoning

The quartz-sulfide vein type of mineralization exhibits a compositional zoning within the Oro Blanco and neighboring Pajarito mining districts (Figure 17). The metal occurrence map has been constructed by determining the dominant base metals in each deposit type and whether economically significant precious metal amounts are present. This has resulted in the nine groups of metal associations shown in Figure 17. Although this is not the most ideal way to classify the veins in that it includes elements of both a compositional and an economic classification, it does serve very well to point out the zonal distribution of vein composition in the district. Silver to gold ratios have been determined for several deposits in the district (Figure 17). These are based upon production figures and multiple assays and in a general way seem to support the zonal pattern suggested by the metal occurrence map. The silver to gold ratios are somewhat erratic because there is no adequate way of evaluating the degree of secondary enrichment or impoverishment of the silver values. This problem is especially acute in a district such as Oro Blanco where many of the deposits have produced only from oxidized ores.

The overall zoning in the district ranges from probable high temperature zones of lead-zinc-copper mineralization through lead-zinc-silver and lead-silver to the low temperature gold deposits having some silver. The zoning is also reflected in the percentage of sulfides in the veins. In the higher temperature zones the percentage of sulfides is high, generally 25 percent or more, whereas in the gold-bearing veins on the fringes of the district the original sulfide content is low, rarely more than 1 percent.

The zonal arrangement of vein types in the Oro Blanco and Pajarito districts seems to be related to two or possibly three separate centers. One center is at the Warsaw mine in the south central part of the Oro Blanco district, a second center is at the Montana mine near Ruby, and the third which may be a part of the second center is in the western part of the Pajarito Mountains. A distance of about 6 miles separates the last two centers, most of which is covered by post-mineralization volcanic rocks. The mineralization center at Ruby is less intense than the other two, being a lead-zinc-silver zone rather than lead-zinc-copper which suggests that the real center is beneath the volcanic rocks east of Ruby. The data are too sparse in the Pajarito district to determine whether the intensity of mineralization changes as one approaches the cover of Tertiary volcanic rocks to the west.

The zonal arrangement near Ruby suggests that a zone of copper-bearing base metal mineralization may lie beneath the cover of Tertiary volcanic rocks. Present information yields few clues concerning the grade of mineralization that might be buried beneath this cover (see Discussion of Mineralization).

The flat-dipping silicified zones and the breccia veins do not seem to fit into the zoning pattern displayed by the quartz-sulfide veins. The breccia veins are known from cross-cutting relationships to be younger than the quartz-sulfide veins, but the only evidence for a difference in age between the silicified zones and the quartz-sulfide veins is this lack of conformity of the silicified zones to the district zoning pattern. Within the silicified zones there seems to be a general decrease in the silver to gold ratios toward the southeast which is just opposite to the change observed in the ratios for the quartz-sulfide veins. The higher ratios in the northwestern silicified zones probably reflect the greater depth at which these formed compared with those in the southeast. This fits well with the northward dip and repetition through faulting of the silicified zones.

The author unsuccessfully attempted to better establish the district zoning pattern by determining the compositional fineness of native gold samples from the various deposits. Gold was separated from samples of crushed vein matter several pounds in weight and the compositional fineness was determined by standard fire-assay techniques. Helgeson and Garrels(1968) indicate that the compositional fineness of native gold should decrease as the temperature of deposition of the gold increases. For this reason the determination of fineness of gold samples throughout the district could contribute to the zoning pattern. Samples of native gold from 10 different mineralized areas in the central part of the district ranging in weight from 2 to 9 mg were analyzed to determine the percentage of gold. The fineness values so determined range from 550 to 940. Multiple samples taken from different parts of a single deposit indicate that the local fineness variations are large enough to effectively mask any district-wide variations unless one could average the results of a large number of samples from each deposit. At the Margarita mine two samples gave fineness values of 615 and 775 respectively, whereas all but one of the samples analyzed from the district yielded fineness values in the range of 550 to 775. The one sample whose value is not in this range was exceedingly fine-grained and yielded a value of 940. Probably this high value is a function of the grain size. Finer grained gold particles should be more succeptible to leaching of their silver by weathering than the coarser particles, so that a higher fineness would be expected. In order for the fineness determinations to be of any value in determining the district zoning one would have to make the fineness determinations on samples having the same grain size and analyze a large enough number of samples from each vein so as to average out the variations in fineness within a particular vein.

Origin of the Mineral Deposits

All of the metallic mineral deposits in the Oro Blanco mining district, with the exception of the placers, are epigenetic deposits of probable hydrothermal origin. All mineralization observed in the district is localized in tabular bodies that nearly everywhere cross cut the host rocks eliminating the possibility of a syngenetic origin for any of the deposits. Demonstrating that the deposits are of hydrothermal origin is less straight forward, but based on the similarity of the composition, alteration, and ore textures to other deposits considered to be of hydrothermal origin, then these are likewise probably of hydrothermal origin.

The temperature-depth zone classification of the mineralization would seem to include a range of epithermal through mesothermal according to the modified Lindgren scheme of classification. The mineral· assemblage sphalerite-galena-pyrite-chalcopyrite-tetrahedrite that occurs at the Montana mine and several other mines in the district indicates a mesothermal classification for these deposits. The manganiferous-lead-silver veins in the southeastern part of the district probably correspond to the leptothermal classification. Those veins which are characterized by a low percentage of sulfides and have significant precious metal content fit well into the epithermal classification. This group would include not only those deposits on the fringes of the district such as the Yellow Jacket and Ostrich veins, but all of the breccia vein type of deposits in the south central part of the district.

The flat-lying silicified zones are also considered to have formed in an epithermal environment. This is suggested by the very low percentage of base metal sulfides, the relatively small size of the mineralized areas, and the fairly high content of gold and silver.

The breccia veins have most certainly been formed in an epithermal environment as evidenced by the abundant open space, the sparse sulfides, and possibly the relationship of ore bodies to the present watertable and topography. This relationship may however be the result of supergene processes rather than deposition in an epithermal environment. These veins are considered to have formed at a much lower temperature and nearer to the surface than the silicified zones.

Discussion of Mineralization

Mining districts of Arizona commonly contain Laramide plutonic rocks that seem to be genetically related to the mineralization (Damon and Mauger 1966), particularly those districts where porphyry copper mineralization occurs. No such intrusive body is directly relatable to the mineralization at Oro Blanco. The Warsaw quartz monzonite and the Ruby diorite are clearly much older than the mineralization, and the only other likely candidate, the Sidewinder quartz monzonite, is definitely younger than the mineralization. In addition no sulfide minerals whatsoever have been seen in the Sidewinder quartz monzonite. If an igneous source exists for the mineralization in the district then it must either be concealed below the present level of erosion or be hidden beneath the cover of Tertiary volcanic rocks. The mineralized area involved in the district zoning pattern of the Oro Blanco and Pajarito mining districts extends over a distance of at least 20 miles in a northwesterly direction. Such an extensive zoning pattern would probably be developed around a genetically related intrusive body only if the present level of erosion has reached the intrusive body or if the body is very large. It seems likely that if a plutonic source rock exists for the mineralization in the Oro Blanco area, it was probably truncated by erosion prior to emplacement of the Tertiary volcanic rocks and should lie immediately below the volcanic rocks.

Actual geologic information concerning the rocks beneath the Tertiary cover is lacking. A residual Bouguer gravity map (Figure 22) obtained graphically from a complete Bouguer gravity map (Hench 1968) shows four positive anomalies using a density value of 2.45 g/cm^3. One of these lies near Ruby and perhaps is due to the high density Ruby diorite, two others lie along a northwest line in the area covered by Tertiary rocks. The latter may represent another body of Ruby diorite, large buried hills of andesitic Montana Peak Formation, or an increased thickness of Montana Peak Formation deposited at the base of a northwest-trending fault scarp. Other than this no direct evidence exists concerning what lies beneath the Tertiary rocks.

Several geologic characteristics of the Oro Blanco area point to a hidden plutonic rock source for the Oro Blanco

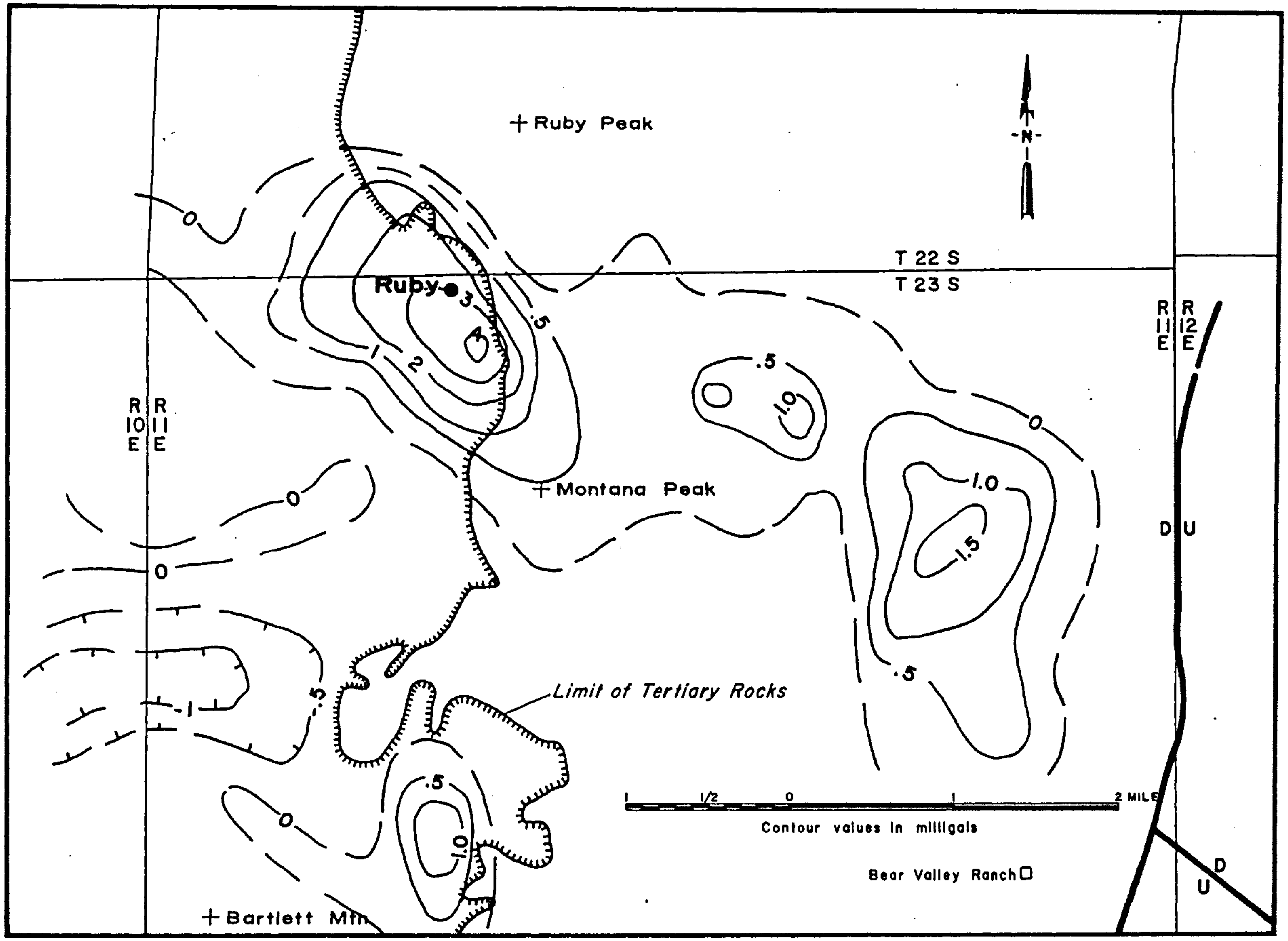


Figure 22. Residual Bouguer Gravity Map, Density = 2.45 g/cm³

mineralization and possible porphyry copper mineralization beneath the Tertiary rocks. These are as follows:

1) The percentage of original sulfides in the quartz-sulfide veins increases southeastwards towards the Tertiary cover.
2) Silver to gold ratios in the quartz-sulfide veins increase towards the Tertiary rocks.
3) The deposits range from gold mineralization in the northwest through silver-gold to lead-zinc adjacent to the Tertiary rocks.
4) The tonnage of orebodies is greatest at Ruby near the Tertiary cover.
5) The number and size of Sidewinder quartz monzonite dikes is greatest adjacent to the Tertiary rocks.

Lowell and Guilbert(1969) note that the porphyry copper deposits of southwestern United States generally are surrounded by a zone of vein type deposits that are characterized by lead-zinc and precious metal mineralization, and by non-pervasive, spotty propylitic alteration similar to that observed at Oro Blanco. The mineral zoning displayed by the porphyry copper districts, that is, increase in mineralization intensity towards the genetically related plutonic rock, resembles the zoning at Oro Blanco. The Sidewinder quartz monzonite dikes may be post-mineralization offshoots of a Laramide quartz monzonite body beneath the Tertiary volcanics. This would explain their greater abundance and size near the Tertiary cover.

The geometry of the mineral zoning pattern in the Oro Blanco area might be defined better by study of any mineralization in the unmapped areas to the north and east of the Oro Blanco district where Mesozoic rocks crop out, such as northeast of Chimney Canyon and in the Peñasco Canyon areas (Figure 13). Such work would probably not greatly change the shape of the zoning pattern but might aid in defining its center. The northwest elongation of the mineralized area is typical of districts in southern Arizona. Examples include the Ajo, Silverbell, and Pima mining districts.

Based upon presently available information the most likely area for the occurrence of mineralization beneath the Tertiary rocks is on a northwest-trending belt about 2 miles in width which lies on the strike projection of the northern belt of northwest-striking faults (Figure 17). The depth of overburden here is estimated to be about 1,500 feet based on projection of the Tertiary units. Geophysical techniques such as induced polarization should be applicable to the search for sulfide mineralization in and adjacent to the hypothesized Laramide pluton beneath the Tertiary cover.

Economic Potential of the District

Examination of a large number of the mines and prospects in the Oro Blanco district indicates that the mineral deposits, although locally of good grade, are relatively nonpersistant features both laterally and in depth so that individual orebodies are of very small tonnage. The largest tonnage produced from a single mine is a little over 770,000 tons and this is indeed exceptional for this district where few other properties have produced more than 10,000 tons. The limited tonnage in known deposits would rule out exploitation by a large company.

In general the district would be no more favorable for the small miner than the large company. The chances of locating any outcropping ore deposits in the district that are of economic value are negligible in view of the intense combing of the district by prospectors for nearly a century. Furthermore the cost of exploring for the small high grade orebodies that might remain undiscovered in existing prospects and mines would likely be more than the value of the orebodies.

The only area where significant undiscovered mineralization may be found is beneath the cover of Tertiary rocks east of the Oro Blanco district.

In summary, the future of the Oro Blanco mining district as a mining area looks dark unless significant mineralization is found beneath the Tertiary rocks.

Influence of the Collapse Structure upon Localization of Mineralized Districts

Mayo(1958), Schmitt(1966), and Wertz(1966) stress the importance of major structural intersections in the localization of mineralized districts in Arizona. These authors have stressed the importance of the west-northwest trending Texas lineament as an ore localizer where it is crossed by lineaments of other trends. Study of the axes of elongation of Laramide igneous intrusive bodies some of which seem to be genetically related to mineralization (Mauger and others 1965) indicates that the axes trend N 7° W to N 55° W. Search through published literature on mining districts in Arizona and Sonora reveals a northwest elongation of porphyry copper mineralization for those deposits within or on the strike projection of the collapse structure discussed under STRUCTURE. The directions of elongation of the deposits are:

Ajo	N 32° W
Cananea	N 32° W
Esperanza	N 65° W
Mineral Park	N 33° W
Silver Bell	
El Tiro	N 30° W
Oxide	N 72° W

If the N 75° W trending Texas lineament has been significant as an ore localizer, why is it not reflected in the orientation of the mineralization and the genetically related plutons? It is the present author's contention that the primary controls on ore localization, at least in southernmost Arizona, are the northwest-trending lineaments (the Walker zone, the southwest Arizona belt, and the central Arizona belt), and the associated northwest-striking normal faults produced during regional collapse. Intersection of these features with northeast-striking lineaments and faults may result in localization of mineralization at specific points along the northwest trends. This suggestion is supported by the very common occurrence of veins and veinlets of northeast strike in the mineralized areas (Lowell and Guilbert 1969).

GEOLOGIC HISTORY

The first record of the geologic history of the Oro Blanco mining district begins with the emplacement of the Cobre Ridge tuff in Jurassic(?) time. The rhyolite member was deposited in a fairly large basin that was supplied by older tuffaceous materials. The extremely poor sorting of the crystal fragments in this unit attests to the rapid deposition of the member. The basin at any given time must have been shallow so that the expelled ash flow tuffs in the lower part of the rhyolite member would not be chilled to such a degree to prevent welding of a considerable thickness of the rock.

After several thousand feet of the waterlain tuffs had been deposited a thick sequence of ash flow tuffs erupted from an unknown source. These apparently poured forth intermittantly as evidenced by the thin wind-blown sandstone units that are interbedded with the ash flows. Some of the ash flows were of sufficiently high temperature and of sufficient thickness that strongly welded zones were formed. After the ash flow eruptions ceased the area was subjected to a period of erosion during which time a thick but laterally nonpersistent granitic arkose was deposited. Possibly other Jurassic units were deposited on top of the arkose, but these have been removed by subsequent erosion. The Warsaw quartz monzonite then intruded the three members of the Cobre Ridge tuff. The presence of the quartz monzonite at the top of the exposed part of the arkose member suggests that other rocks must have been deposited here in Jurassic time but have been removed by erosion. The intrusion of the Jurassic(?) quartz monzonite, the faults having a north-northeast strike that developed after emplacement of the quartz monzonite, and the uplift of the district at this time probably occurred during the Nevadian orogeny.

After uplift of the area and a period of considerable erosion that produced a landscape characterized by canyons several hundred feet in depth, the Lower Cretaceous(?) Oro Blanco formation was deposited. The basal member, the Oro Blanco Conglomerate, was deposited in steep-walled channels and as talus piles at the foot of slopes developed on the underlying Cobre Ridge tuff. Farther out from the topographically high areas finer-grained materials were deposited in alluvial fans. The extremely poor sorting and the interbedding of coarse and fine-grained units was caused by the rapidly changing courses of the streams that deposited the clastic materials, much as with present day alluvial fan deposits. The environment of deposition was certainly terrestrial and the climate was appropriate to permit extensive oxidation of some of the finer-grained beds to form red beds. The presence of dark-green and locally dark-gray silty beds interbedded with the red beds shows that the climate must have been humid enough to allow swamps to form, but the lack of any fossil remains and poor sorting of the clastic grains speaks for transportation by intermittant streams. Probably the climate during

Early Cretaceous time was quite similar to the present but slightly more humid.

In a part of the district a small enclosed drainage basin must have formed which was occupied by a playa that was at least four miles across. In this playa were deposited a few thin beds of poorly sorted gravels, sandstone, and siltstone, probably at times of flooding. As the lake water evaporated the calcium carbonate precipitated out to form the thin limestone member of the Oro Blanco formation. Probably certain types of algae are responsible for the carbonaceous material that blackens the member. Such an origin would account for the extreme variability of the limestone along strike and its resemblance locally to present day caliche-cemented gravels.

Sometime after deposition of the Oro Blanco formation a thick sill of Ruby diorite and a thinner sill of andesite intruded the Oro Blanco formation. These intrusions were sufficiently forceful to cause some crumpling of the Oro Blanco formation. It was also at this time that the northwest-trending lineation formed in the diorite. The attitude of the lineation suggests a lateral stretching in the diorite that is parallel to the bedding in the Oro Blanco conglomerate, exactly what one would expect to find in a sill. This same direction of stretching is reflected in the numerous northeast quartz veins that cut the lineation at nearly right angles, for these seem to be quartz-filled tension fractures.

The next event in the history of the district is the Laramide orogeny. This may have been initiated as a very local uplift southeast of the Oro Blanco district that produced the first movements on the northeast faults. Probably the orientation of these structures is reflective of the northeast structural grain in the Precambrian basement. Next came renewed movement on the north-northeast striking faults, the cause for which is unknown at this time. The climax of the Laramide orogeny was the formation of the large collapse structure that may have originated from lateral extension of the crust away from a deep-seated zone of weakness. The formation of the collapse structure may have been related to movements in the East Pacific rise beneath the Basin and Range Province.

The large displacement northwest faults experienced their main period of movement during the formation of the collapse structure. This movement tilted the Mesozoic rocks southwestward. This southwestward tilting and the faulting have resulted in extensive repetition of the Mesozoic units throughout the Oro Blanco district and much of Pima and Santa Cruz Counties.

After most of the movements on the northwest-striking faults had ceased numerous blocks within the collapse structure again became mobile, probably in an attempt to achieve an isostatic condition. Differential rates of movement within the blocks along a northwest line may have set up shearing stresses in the blocks that led to renewed movements of the established northeast faults and the formation of new northeast faults.

The next event, the one of most economic significance, is the period of mineralization. During this time all of the base and precious metal deposits of the Oro Blanco mining district were formed. The mineralization began with the deposition of quartz in pre-existing tension cracks, in breccia zones adjacent to major faults, and as replacements of fault zones. The principal metallic mineralization then formed as cavity fillings and replacements in the quartz veins. The general order of deposition of the metallic minerals is pyrite, sphalerite, chalcopyrite, tetrahedrite, and galena, from oldest to youngest. Native gold occurs in many of the veins, but its position in the paragenetic sequence is unknown. The main mineralization was deposited in two types of structures, steeply to moderately dipping quartz-sulfide veins and flat-dipping pyritic silicified zones. A slight amount of displacement of some of the flat-dipping silicified zones occurred after mineralization. The resulting small displacement fault zones and the joints became the site for late-stage precious metal mineralization, that is characterized by intrusive(?) breccia zones mineralized by small amounts of vuggy quartz, native gold, and silver in unknown form.

In Early Tertiary time after mineralization, a period of andesite to dacite volcanism and quartz monzonite intrusive activity dominated the Oro Blanco district. During this time the numerous Sidewinder quartz monzonite dikes intruded the district principally along pre-existing fractures and veins. Simultaneously the andesite member of the Montana Peak Formation was erupted. Shortly after the emplacement of the Sidewinder dikes a few dikes of Blue Ribbon andesite intruded the Montana mine area. Probably after the Blue

Ribbon intrusion period was complete the upper four members of the Montana Peak Formation were emplaced. During or shortly after the emplacement of the lower dacite tuff member renewed slippage occurred on the northwest and northeast faults that sheared many of the Sidewinder quartz monzonite dikes and brecciated many of the mineralized zones. The resulting breccias were then cemented with barren calcite and quartz and numerous barren silicified patches were formed in the Montana Peak Formation in the southernmost part of the district. This late stage of barren mineralization may be related to the extensive rhyolite volcanism in mid-Tertiary time.

When the Montana Peak Formation volcanism ceased, the area was again eroded so that much of the upper two members of the Montana Peak was removed.

In Late Oligocene time the rhyolites of the Atascosa Formation were erupted. The initial eruptions consisted of flows, but later an ash flow tuff unit was erupted which was again followed by flows. These volcanic rocks seem to have been emplaced by eruption along many northwest fissures that are now preserved as a swarm of rhyolite dikes composed of rhyolite lava and tuff. One small vent near the International Boundary may have supplied some of the volcanic materials. The volcanism was very extensive, covering many tens of square miles with tuffaceous materials, both welded and nonwelded.

The volcanic rocks were then eroded and the interbedded gravels and tuffs deposited from the debris probably during Miocene or Pliocene time. One major north-northeast fault east of the Oro

Blanco district was reactivated. Drag on this fault formed a gentle syncline in the Tertiary rocks at the eastern edge of the district.

Recent uplift has stripped much of the Tertiary volcanic cover from the district and resulted in secondary enrichment of the silver and copper values in some of the mineralized veins. In addition the gravels of the pediment areas and the present day streams have been deposited.

CONCLUSIONS

Study of the district and regional geology, as well as a few radiometric dates in rocks outside of the Oro Blanco district, indicate that the rocks exposed in the Oro Blanco mining district range in age from probable Jurassic to Late Tertiary.

The structure of the district is dominated by southwestward tilted fault blocks which are separated by normal faults having three major directions of strike, north-northeast, northeast, and northwest. The tilting of the fault blocks is the result of displacements on the northwest faults. The major faults, those of northwest strike, originated from crustal extension of about 25 percent along a northeast line. This crustal extension is evident throughout most of Pima and Santa Cruz Counties in the form of a large northwest-trending collapse structure. This collapse structure formed mainly during the Late Cretaceous to Early Tertiary Laramide orogeny, but some movement may have continued into mid-Tertiary time.

The presence of the collapse structure of Laramide age indicates that the Laramide orogeny of southern Arizona was not characterized by lateral compression, but instead by lateral extension. In addition some of the Basin and Range faults of southern Arizona formed during this extension and experienced only minor adjustments during the Basin and Range orogeny.

Three major types of metallic mineralization have been recognized as of Late Cretaceous to Early Tertiary age in the district. The emplacement of the mineralization followed the development of the major faults, but preceded the first Tertiary volcanism. Other mineralization of very minor importance and barren of metallic minerals includes quartz-tourmaline veins of Jurassic(?) age and calcite and quartz veins of Tertiary age.

The metallic mineralization is hydrothermal in origin and ranges from mesothermal to epithermal in environment of deposition. Both base metal and precious metal deposits have been formed.

Localization of ore bodies has been principally in dilational zones in and adjacent to major faults. Intersection of major northwest faults with northeast cross faults may have localized a few orebodies. The Oro Blanco conglomerate member seems to be a favorable host rock probably because of its ease of fracturing and high original permeability.

Most ore deposits exploited in the past have been characterized as nonpersistant features both laterally and in depth so that the tonnage available for a given deposit is generally small, rarely over 10,000 tons, although one deposit in the district is credited with a production of a little more than 770,000 tons.

Post-mineralization faults have displaced the mineralization in a few areas. Late movements on both the northwest and northeast directions of faults have offset some of the mineralized zones.

Post-mineralization quartz monzonite dikes have intruded the ore zones making their exploration and exploitation difficult.

The future economic potential of the Oro Blanco mining district is poor unless exploration beneath the cover of Tertiary rocks east of the district discloses significant mineralization.

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8 maps for this thesis have been mylar encapsulated, and are presently located elsewhere. on top of photograph files 3/89