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Geology of Cienega Mining District, Northwestern Yuma County, Arizona

Elias Zambrano

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GEOLOGY OF CIENEGA MINING DISTRICT,
NORTHWESTERN YUMA COUNTY, ARIZONA

BY

ELIAS ZAMBRANO, 1936

A

THESIS

submitted to the faculty of the

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ABSTRACT

In the mapped area three metamorphic units crop out: calc-silicates and marble, gneiss, and a conglomerate-schist section. The first one consists of a series of intercalations of calc-silicate rocks, local marbles, and greenschist. Quartzite appears in the upper part of the section. This section passes transitionally to the gneiss, which is believed to be of sedimentary origin. Features indicative of sedimentary origin include intercalation with marble, relic bedding which can be observed locally, intercalation of greenschist clearly of sedimentary origin, lack of homogeneity in composition with both lateral and vertical variation occurring, roundness of zircon grains, and lack of zoning in the feldspars. The third unit consists of metamorphosed conglomerate, quartz-feldspathic schist, and impure quartzite. The major differences from the first unit are the lack of marble and the presence of conglomerate. A series of basic dikes cuts across the gneiss. All of these metamorphic rocks are believed to be Paleozoic in age. Tertiary-Cretaceous sediments consisting of unmetamorphosed reddish conglomerate, sandstone, and siltstone outcrop in unconformable and fault relationships with the older rocks of the area. Also
unconformable upon the older rocks is a series of tuffs and basalts of Quaternary age.

A northwest-southeast horizontal compression has produced two anticlines, several vertical faults and some shear zones. A new set of structures including thrusts, reverse faults, and a nappe of marble over Tertiary-Cretaceous sediments was produced by a new stress perpendicular to the first one.

Iron and copper mineralization occurs in the area. The order of mineralization was sulfides (chalcopyrite), supergene sulfides (bornite, covellite, and chalcocite), iron mineralization (hematite), and oxidation producing copper carbonates (malachite and azurite). The mineralization was controlled by local fracturing, with no major ore related to regional structure. The marbles served as good stratigraphic control for iron replacement deposits. Gold has been mined from vein deposits at several localities in the area.
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## Plate:

1. Geology of the Cienega Mining District, Arizona (in back)
CHAPTER I
INTRODUCTION

A. Purpose and Scope

The purpose of this investigation was to determine the general geology of an unusually complex area containing several small mines and located in the northwest corner of Yuma County, Arizona. This report is the first attempt to work out in detail the lithology, structure, stratigraphy, petrography, and economic geology of the area.

B. Location and Accessibility

This area is located in the northwest corner of Yuma County, Arizona, close to the entrance of the Bill Williams River into the Colorado River (Fig. 1). It occurs within a rectangular area whose four corners are: 140° 11' 12" longitude, and 34° 98' 36" latitude; 140° 13' 48" longitude, and 34° 11' 30" latitude; 140° 6' 46" longitude, and 34° 12' 17" latitude; 140° 10' 12" longitude and 34° 13' 48" latitude. The Buckskin Mountains occur to the east of the area and it is in the western part of the Santa Maria (or Bill Williams) Mining District.

The area is accessible from State Highway 95 which passes through the town of Parker and along the east bank
Fig. 1. Location of Thesis Area.
(State of Arizona)
of the Colorado River. From this highway several gravel roads lead to the various mines scattered through the area. These roads make all of the area easily accessible.

C. Climate

The climate is warm and arid. In 1964 the temperature went from $23^\circ F$ in January to $117^\circ F$ in July. The average temperature was $73^\circ F$, and there were 2.02 inches of rainfall. During June and July it is cold at night but in August the nights are hot and sand storms are usually frequent. Vegetation is sparse. It includes various species of sagebrush, cactus, and yuca. Wildlife consists of small rodents, snakes, coyotes, and numerous types of birds. Elevations in the area vary from 400 feet at the Colorado River to 1,600 feet near the Carnation Mine.

D. Methods of Investigation

Field work was carried out during June, July and August of 1964. It was conducted using topographic maps published by the U. S. Geological Survey at a scale of 1:24,000. Low flight airphotos were also used. In general all transverses were made perpendicular to strike using a Brunton compass and hand lens to study the outcrops. Much of the work was conducted along washes in order to
get in areas with fresh samples, although some transverses were made across the hills.

Laboratory investigations consisted of petrographic study of 25 thin sections and of seven representative mineralized samples by the techniques of ore microscopy.

E. Acknowledgment

Thanks are due to Dr. Paul Dean Proctor, Chairman of the Department of Geology and Geological Engineering, and to Dr. A. H. Brownlow for their advice during the work of this thesis. The author also extends his appreciation to fellow students for their kindness, friendship, and help during the undertaking of this problem. He wishes to thank Dr. Joe Jemmett of the Simplot Company who lent him airphotos and topographic maps. Mr. Vernon Pick kindly provided financial support and encouragement.
CHAPTER II
TOPOGRAPHIC FEATURES AND DRAINAGE

The whole state of Arizona lies within two of the major physiographic provinces of the southwestern United States (Fig. 1). The area of this study lies within the Basin and Range Province, which is characterized by intense deformation with numerous relatively elevated and depressed blocks. The area occurs within the Desert Region of the Province. Another characteristic of this Province is the pediments, the semi-planar, locally hilly, rock-cut surfaces which are believed to be a result of lateral planation by streams and partly of sheet-flood erosion or faulting in some cases.

In this area (Plate I) the elevation ranges from 400 feet at the Colorado River up to 1,000 feet on the basalt plateau and Rio Vista ridge, to 1,200 feet on Billy Mack Mountain and up to 1,600 feet northeast of the Carnation Mine, in the east corner of the map. This is the highest elevation in the mapped area.

All these topographic features have their origin in geological structures and rock types that are able to support higher elevations or are reduced to pediment by
lateral erosion. For instance, the valley separating Lion Hill and Rio Vista ridge is a fault zone now covered with alluvium that can be traced for almost three miles and extends to the southeast forming an extensive pediment out of the area. The Rio Vista ridge has the same trend and its origin is due to the fact that it follows the general trend of the rock units, besides representing the downthrow block of a vertical fault.

The topographic plateau is due to horizontal basalt flows which are resistant to erosion and apparently have not been disturbed. It is dissected by a series of young small washes with V-shaped valleys. In some of them a vertical cliff has developed but in others an accumulation of colluvial material is present. The gneissic area supports relatively low topography and its gradient is toward the north at almost 15 percent. It is a more dissected area and the main washes, unlike the small tributary ravines, are not perfectly V-shaped, but possess floors (Fig. 2). Some of them have mapable alluvial deposits in the lower part close to the confluence with the Colorado River.

Billy Mack Mountain structurally is the north side of an uplifted tilted block that has the trend of the
Figure 2. Panoramic view of area looking NE from Sue Mine.
marbles in that specific area. The north side is a sharp cliff due to the fact that greenschists occur here and are not able to support such elevations. The south side is limited by a vertical fault that puts into contact the marbles and the gneiss, forming a graben structure and depression between Billy Mack and Lion Hill.

Lion Hill is the crest of an anticline whose north side is limited by a vertical fault, with the south side limited by a series of horizontal flows. The highest elevations in the area are in the east part where marbles that are resistant to erosion reach the crest of an anticline.

In the east-central part of the area there is a low undulating terrain supported by gneisses which are badly weathered. It is believed that the area was covered by water long enough to weather the rock but without deposition of any sediments. This is the north border of the semi-aquatic environment in which the Tertiary-Cretaceous sediments were deposited.

Thus all the topographic features have their origin in faulting, folding, rock type, erosion, and environment through geological time. There are small topographic
features, due mainly to recent mechanical erosion since chemical weathering is almost absent in this desert area.

The main drainage channel is the Colorado River which sends its waters to the Gulf of California. The mapped area has two systems of drainage: those washes trending northwest that form a parallel system and enter directly into the Colorado River; and another dendritic system which is formed from water coming from the plateau zone and going south to form the Osborne Wash, which in going out of this area makes a northwest turn to join the Colorado River.
CHAPTER III

GENERAL GEOLOGY OF THE AREA

A. Regional Geology

The following summary of the regional geology of Arizona is taken from Bancroft (1911), Darton (1925), and Wilson (1962). Rocks of all ages can be found in Arizona from Precambrian to Cenozoic, although not all the events that characterized these ages can be recognized from place to place. Dating has been based on geochemical age determinations or fossils, and indirectly by stratigraphic relations.

Structural features have been developed throughout geological time and horizontal compression has produced shear fractures, folds, thrusts, strike-slip faulting, normal faults, and tension fractures. All these features tend to follow systematic directions. For instance, the major folds have been developed in four general directions: NE-SW, NW-SE, N-S, and E-W. Some of these directions are dominant within a specific area, for example, in the Precambrian the main folding is NE-SW; but in Laramide time it is N-S and NW-SE predominantly.
1. Precambrian

Precambrian time has been divided on the basis of the Mazatzall revolution into two series, the older Precambrian characterized in the northwestern part of the state by schists, quartzite, metamorphosed sediments and volcanic rocks, and young Precambrian which has not been recognized in the northwestern part of the state but in the north is represented by the Grand Canyon Series. The Mazatzall revolution was marked by a series of intrusions ranging from granitic to gabbroic in composition.

Structural developments during this time are due to the Mazatzall revolution which produced a major folding trending northeast and locally northwest; thrust faults and steep reverse faults trending parallel to the folds; and steep northwesterly faults. The economic features of this age are related genetically to igneous intrusives of the Mazatzall period. Pegmatite deposits were common during this era and also the Precambrian rocks are the hosts for the copper, zinc, lead, silver, and manganese deposits of Laramide (Late Cretaceous-Tertiary) age.

The schist and gneiss of the mapped area are generally believed to be Precambrian but may be Paleozoic. They turn
out by structural analysis to be younger than the calc-silicates and marbles that underlie the gneiss.

2. Paleozoic

The Paleozoic beds are dominantly marine calcareous deposits in the south part of the state but northward the upper part includes units of continental sandstone and shale. In general the Paleozoic occurs most extensively within the Plateau and Transitional zone (Fig. 1). It is relatively absent from the Basin and Range Province. Repeated invasion and withdrawal of the seas characterized the geologic periods up to Permian. The life in this era included brachiopods, mollusks, corals, trilobites, fishes, and crinoids.

Igneous rocks belonging to this era are lacking in Arizona. There are no metaliferous deposits of Paleozoic age. This may be because there are no intrusives of that age either. However, Paleozoic rocks are often hosts for mineralization that is regarded as Laramide.

One relevant feature of this era is the Permian-Triassic unconformity which is great throughout the Plateau Province (Fig. 1). Within northeastern Arizona, the hiatus becomes progressively greater from west to east.
3. Mesozoic

The sedimentary rocks belonging to this era include sandstone, shale, conglomerate, and minor limestone. Their environment of deposition ranges from non-marine to near-shore and marine. Igneous and metamorphic rocks of this era are known or inferred particularly in southeastern and southwestern Arizona. During Triassic and Jurassic time red beds were deposited along the margin of seas that existed to the north and northwest, with streams flowing from the highlands in central and southern Arizona depositing mud and sand such as the Chinle formation that occurs in the Painted Desert. After Jurassic time there was a period of erosion that produced a great unconformity extending from northeastern Arizona to the southwest. This surface served as the basin for Cretaceous deposits characterized by marine, near-shore, and continental types. Interbedded with these sediments at some localities are volcanic rocks, which implies crustal unrest.

In Yuma County the Castle Dome and Kofa Mountains contain deformed flows, breccias and tuffs of the Cretaceous period which lie unconformably upon Triassic and Jurassic sediments.
In the late Cretaceous and early Cenozoic there was a period of mountain building deformation, uplift, and igneous activity called the Laramide or Rocky Mountain Revolution. It was most intense in the Basin and Range Province of Arizona (Fig. 1), producing a series of open folds of dominantly northwest to northward trend, and a series of faults ranging from normal, reverse, and strike-slip to thrust types. The major intrusives of this revolution are batholiths and stocks ranging from granitic to dioritic in composition, followed by dikes, hills, and plugs of widespread occurrence which range from acid to basic in composition.

Sedimentary rocks of reddish-brown to gray color, some of which are conglomerate, sandstone, arkose, shale, and local thin limestones, occur intercalated with basalt and andesite that rest unconformably upon Precambrian or Paleozoic rocks. These have been designated as Tertiary-Cretaceous Sediments (T.K.S.) in the Yuma County Geological Map published by the Arizona Bureau of Mines in 1960.

The economic deposits associated with this revolution are some of the most important throughout the western United States. Many ore bodies in Precambrian, Paleozoic and Mesozoic host rocks were formed. They are controlled
and localized by Laramide structural features, and are genetically associated with stocks of monzonitic composition. In some cases they themselves are host rock for hypogene mineralization.

4. Cenozoic

Tertiary and Quaternary sediments are wide-spread and cover a large area of Arizona, especially in the Basin and Range Province. Most of them are continental in character. Because of this fossils are scarce and the sequence of events difficult to trace. Thus ages have been assigned by indirect evidences. Also, structural details tend to be obscured by the difficulty of finding persistent marker beds in the sediments and by discontinuity of members of volcanic sequences.

Representative sediments are clay, sandstone, gravel, shale, and lake deposits. They are associated with volcanic flows, which are intercalated with sediments of late Cenozoic in many places.

Igneous activity is represented by late Miocene or early Pliocene lacolithic intrusions, cones, necks, plugs, and dikes that intruded along fissures or other weak zones. Eruptive rocks are common at many places, coming from central vents.
One economic feature of this era is the sedimentary manganese beds of Pliocene age in the Artillery Peak area of Mohave County. They are of low grade but have been mined recently. Other features of economic importance are a number of gold placers which occur associated with Cenozoic pediments. Oxidized copper minerals of placer origin are mined from the Whitetail Conglomerate in the Copper Butte area.

B. Lithology and Stratigraphy

The rock units that outcrop in the area are related to two major anticlines, one in the eastern part and another in the central part of the area. There is a series of vertical faults in the central part and a thrust fault in the east and another in the west (Plate I).

The rock units that outcrop in the mapped area can be divided into two general groups, the metamorphosed units and the unmetamorphosed rocks of supposedly Tertiary-Cretaceous age. The first consists of three main units, calc-silicate rocks, gneissic rocks, and metamorphosed conglomerate-schistose rocks. Besides these, there is a series of metamorphosed basic dikes within the gneissic rocks. The calc-silicate rocks pass transitionally into the other two units.
The unmetamorphosed section consists of a series of interlayered conglomerate, arkose, sandstone, shale, mudstone, and siltstone. There is a small outcrop of andesite within this sequence which is mineralized at a fault contact at the Sue Mine. Tuff and olivine basalt lie unconformably on these sediments.

The youngest material of the area consists of gravel and alluvial deposits of very recent age.

1. Metamorphosed Units

The oldest rocks in the mapped area are the interlayered marbles, schist, and quartzites. The marbles are impure limestones, and thin section work shows the percentage of calcite to be about 20 percent with a high percentage of quartz. Other mineral constituents are feldspar, epidote, and muscovite. Opaque ore is hematite and when altered produces limonite. Hence, what seemed to be marbles in the field are really calc-silicate rocks. It is very common to find microfolds where the resistant quartz microlayers form sharp edges. The marbles can be traced in the area for long distances on the airphotos and can be used as stratigraphic guides.

The bottom of the calcareous section starts with a massive impure marble which is mineralized in the Rico
Mine area. Overlying it is a greenschist whose upper contact is a vertical fault against the gneiss. Thus most of the upper part of this section is lacking in the central anticline. Immediately after the faulted wedge of gneiss, the calcareous section continues with a massive impure marble that forms Billy Mack ridge and is about 700 feet thick. This horizon is mineralized on the north side and represents the host rock for mineralization at the Billy Mack Mine. Overlying it is another greenschist horizon which is one of the thickest in the region and forms the floor of the valley north of Billy Mack Mountain. The mineralogical composition of the schist is quartz, orthoclase, microcline, albite, chlorite, calcite, muscovite, hematite. Accessories are tourmaline and rounded zircon. Alterations include limonite coming from hematite and sericite from feldspar. This mineral assemblage suggests that the grade of metamorphism is not greater than that of the greenschist facies. Overlying the schist there is a section of interlayered, impure marble and schist whose lateral extension in the central anticline locally changes in facies toward the east where the rocks get more siliceous and argillitic. Quartzite and greenschist are more abundant and the marbles get more lenticular.
In the upper part of this section a quartzite appears interlayered with the impure marble. Actually, the quartzite develops into a quartz-feldspar-mica schist, so that they have a transitional relation. The association of quartzite and marble is something common from the sedimentation point of view since the marble, as well as the schist, has a relatively high content of quartz. The most important point is that this quartzite could be interpreted as representing the initial change in the environmental conditions that made possible the transition from the relatively deep calc-silicate environment to those of shallow zones of arkose sandstone that now are represented by the gneiss.

The contact is not only transitional from a depositional point of view but structurally also (Fig. 3) as can be seen in the eastern part of the area where layers of marble are intercalated with the gneiss. This also indicates a sedimentary origin for the gneiss. An important difference between the calc-silicate section and the gneiss is the brittle character of the latter, which shows a difficult pattern of deformation when mapping regional structures.

The mineralogical composition of the gneiss is quartz, orthoclase, microcline, albite, biotite, chlorite, and epidote.
Figure 3. Contact of gneiss and marble north-west of Billy Mack Mine.
Opaque ore is hematite. Alterations are sericite and clay minerals from feldspars. Accessories are apatite, garnet, tourmaline, sphene, and rounded zircon. These accessories, especially the rounded zircon, point out the sedimentary origin of the gneiss. The mineral assemblage could be derived from an arkose sandstone. Interlayered with the gneiss there is a series of greenrocks whose composition is quartz, epidote, biotite, hornblende, sphene, and feldspar. The main accessory is apatite. Alteration products include chlorite and clay. These beds are easily recognizable in the field and can be followed for long distances. Their relation with the gneiss is that of bedding, which still can be noted despite the metamorphism. This is not of high grade, as deduced from the mineral assemblages characteristic of the greenschist facies. Their stratigraphic distribution is very difficult to determine, as well as the sequence of gneiss as a whole, but these greenrocks can be found anywhere within the gneiss, and they are the metamorphic equivalent of shales that were originally interbedded with the arkose sandstone that now forms the gneiss.

There are two spots within the mapped gneiss that represent an acid igneous intrusion of pre-metamorphic age.
These rocks are now acid gneiss. The evidence that this gneiss is of different origin includes the rounded defined shape, the homogeneous lithology, and the grade of alteration of the feldspar in thin section. All evidence of contact metamorphism is obliterated by regional metamorphism. The rock is quartz-feldspar-epidote porphyroblastic gneiss, more leucocratic than the other gneiss. The lateral extension for the bigger intrusion is about 500 feet in diameter and it has a series of tiny manganese veins.

There is a white, quartz-rich, fine-grained rock of mylonitic texture that sometimes appears intercalated with the gneiss and in other places cutting across it. It is sometimes associated with faults as in the north-central part of the area. This rock is a mylonitic rock and its origin can be explained by strong cataclastic deformation of the original arkose sandstone, causing it to reach the melting point. Then the quartz began to separate and intruded through the weaker zones such as bedding planes, fault planes, and also in other places where it was able to cut across the rock and form small veins. This rock is also present in the west part of the area associated with the marble and gneiss contact. It is also at the same contact in the east.
In the south corner of the mapped area (Plate I) is found a series of interlayered conglomerates, quartz-feldspathic-micaceous schist, and quartzites. This is a new unit different from the calc-silicate and marble unit because there is no marble and the schists are more siliceous and micaceous than in the other areas. Also this unit has conglomerates with elongate pebbles.

The regional trend is N30W and the average dip is 40 degrees south. This is the general trend of the south Rico ridge where it outcrops. The contact relationship between this unit and the calc-silicate and gneiss is unknown since the possible contact zones are covered by alluvial material in the mapped area.

The section starts out with a series of intercalated conglomerates, with elongated pebbles due to metamorphism, and quartz-micaceous schist. Three layers of conglomerate about four feet thick were identified in the first half of the section, then the middle part becomes more schistose and laminar and intercalated with some brown impure quartzite. Both rocks have a calcareous matrix in most cases. The rest of the section is even more siliceous and the quartzite gets lighter in color, reaching the white color which means a rather pure quartz-feldspathic composition.
The origin of these metamorphosed rocks is clearly conglomerate sediments, impure sandstone, impure silty rocks, and more pure fine-grained sandstone at the end of the exposed section; these are now metamorphosed to greenschist facies rocks.

The mineralogic composition derived from a few thin section studies shows: quartz, feldspar, mica, calcite, and zircon. The only opaque mineral is hematite. In the field the matrix is especially calcareous in the middle of the exposed unit and siliceous in the upper and lower parts. These rocks reach their maximum thickness to the southwest, outside of the mapped area, where it might be possible to see their relation with the gneiss, and the upper limit with the unmetamorphosed rocks. In these rocks copper and iron ore has been mined.

These three metamorphosed units, the calc-silicates and marbles, the gneiss and the conglomerate-schist section, have not previously been studied in detail, and are not named, as far as the author knows. They constitute definite lithological and stratigraphical units that should be named and defined. This attempt was made but the sections are incomplete in the mapped area and structurally complicated.
The age of these formations is another problem because of the absence of fossils. Darton (1925) states he found Carboniferous fossils in the limestone in the vicinity of Billy Mack Mine. Bancroft (1911) studied the geology of this area and believed that the calc-silicates, marbles, and gneiss are of Precambrian age.

The author believes that the oldest rock unit in the mapped area is the calc-silicate unit since it forms the core of the central anticline and stratigraphically follows the gneiss with a transitional contact between the two. The conglomerate-schist section might be the youngest of this metamorphosed group; where to place the base of this group is a matter of speculation and is beyond the scope of this report, which is the result of the study of a small area. To answer this question more regional studies of all these units are needed. The author places the calc-silicate and marble section in the Paleozoic following the pattern of the last County Geological Map of Arizona (1960), published by the Arizona Bureau of Mines. The gneiss is younger since the upper contact of the marbles are transitional to the gneiss. Other authors have dated the gneiss as Precambrian (Bancroft, 1911) and the marbles as Carboniferous (Darton, 1925). The
metamorphosed conglomerate-schist is supposed to be the youngest unit within the metamorphosed rocks.

There is a series of metamorphosed basic dikes cutting across the gneiss. These were not seen cutting the calc-silicate section or the conglomerate-schist rocks. Since these rocks are believed to be older than the gneiss, the absence of dikes can possibly be explained by the low volume of these rocks. Also the gneiss has fractured more easily and would thus be more likely to have dikes in it. They can sometimes be followed for almost half a mile. Those north of the Well Mine have a general trend which is northwest; some of them are locally dipping about 80 degrees north but they are vertical in most of their extension. Their thickness is about four feet down to one foot in some places. There is a series of smaller dikes in the northwest part of the area, where sills are more common.

The mineral composition of the dikes is as follows: hornblende, andesine, and epidote. Opaques are hematite and magnetite. Accessories are quartz and calcite veins. Their mineralogy reflects their basic composition and resembles that of the intercalated greenschist found in the gneiss. This is due to similar original composition
but different origin, one sedimentary and one igneous. The igneous texture is still visible in a hand specimen although the dikes have been metamorphosed to the same degree as all of the metamorphosed rocks of the area.

2. Unmetamorphosed Units

A series of conglomerates, sandstones, shales, arkoses, and thin local limestones rest upon the gneiss or upon the calc-silicate section (Plate I). These have been mapped as Tertiary-Cretaceous sediments (T.K.S.) in the Yuma County Geological Map published by the Arizona Bureau of Mines. These sediments are supposed to be the same as those named the Artillery formation by Lasky and Webber (1949) in the Artillery Mountains of Mohave County. These authors assigned tentatively an Eocene age for the sediments on the basis of some palm root fossils.

These sediments outcrop in two zones in the mapped area, in the west and in the central part. In both places they rest unconformably upon the gneiss and a small segment upon the calc-silicate metamorphic rocks (Fig. 4). The lower part consists of a boulder conglomerate, made up of pieces of gneiss, marble, granite, schist, quartzite, and basic igneous rock; all in a chaotic assemblage.
Figure 4. Contact of gneiss and Tertiary-Cretaceous sediments at Well Mine.
Some of these boulders, especially the gneissic ones, are 2 to 3 feet or more in diameter. Most of them are angular, but the smaller ones are more rounded and have between them some rhyolite pebbles. This conglomeratic horizon forms a ridge west of the Carnation Mine trending almost east-west and dipping gently toward the south. It is mineralized with copper and a little iron in the area of the Well Mine. The mineralization is in veins and open spaces in the conglomerate. In the same central area this conglomerate is overlain by a series of reddish-brown coarse-grained sandstones interlayered with impure arkose and fine-grained sandstone which in some places is greenish and gray. Thinner beds of shale are intercalated. The upper part has fine-grained sandstone, with interlayering of mudstone, siltstone, and shale which vary in color. This part of the section is thicker than the basal conglomerate. The upper contact is with the Quaternary basalt flows which lie horizontally and unconformably over these sediments.

The T.K.S. section outcrops more extensively in the western zone of the area, lying partly on the gneiss and partly on the calc-silicate section with a thrust fault relationship. The evidence of this thrust is the strike-
slip fault perpendicular to the thrust direction, the straight line direction of the contact and the lack of the basal conglomerate. The lower section is a series of reddish sandstone and arkose followed by thick conglomeratic beds which contain the same kind of material as that of the conglomerate of the central area, but smaller in diameter. This intraformational conglomerate is overlain by a series consisting of sandstone, shale, and mudstone. In this part of the section there is some vein mineralization. The upper contact of these rocks is with Quaternary gravel. These sediments have their lateral continuation toward the Sue Mine area where they lie unconformably over the gneiss. In this area it is very common for Quaternary basalt to cap the T.K.S. sediments unconformably.

Knowledge of environment of deposition of these sediments has to be based on study of features such as color, sorting, rounding, and the nature of the material that constitutes the sediments. The color might be due to the kind of rock that furnished the sediments. The limestone and basic igneous rock are common components of the conglomerate and arkose sandstone and it is known that these rocks tend to yield red soil which when re-deposited produces red sediments. A second origin could
be based on the conditions at the site of deposition, with atmospheric oxygen transforming ferrous to ferric compounds due to dry summers that cause dehydration and an absence of organic matter.

Sorting is very poor in these rocks, especially in the basal conglomerate which is characterized by its chaotic character. This feature is suggestive of rapid deposition with not enough time for sorting of the material. The sandstone and the arkose are a little more sorted due to the fact that the smaller grains do not need too much transportation to become sorted.

The rock has a series of sharp angular pebbles that suggests little transportation. The degree of roundness increases toward the top of the section, not because there was more transportation, but because the grain size gets smaller.

All these factors point out that the rocks that furnished the material for these sediments were those gneisses, schists, marbles, quartzites, etc., that outcrop in the area and that the environment where these sediments were deposited was that of fast deposition and fast subsidence in a littoral or semi-terrestrial zone where sorting of the material was almost nil, and oxidizing conditions
were prevalent. The type of basin for this condition may be that of the basin and range type.

Andesite rock outcrops only in two small parts of the area, at the Sue Mine and along Highway 95 in the northwest corner of the mapped area. At the Sue Mine the contact relationship is a faulted block. Along the highway the contact looks conformable with the T.K.S. sediments. The andesite mineralogical composition is feldspar and less than 5 percent quartz, with a glassy material and some alteration such as chloritization and sericitization. This rock is the host for mineralization together with the T.K.S. conglomerate.

Tuffs and basalt flows rest unconformably over the T.K.S. sediments, the calc-silicate section, the gneiss, and the metamorphosed conglomerate-schist rocks. The lower part is composed of tuffs about 100 feet thick, overlain by olivine basalt almost 500 feet thick. South of the Carnation Mine there are two intercalated layers of ash beds each almost three feet thick. In the southwest zone the intercalation of ashes beds is more conspicuous and here the section reaches its maximum geographic extension and thickness. The thickness becomes greater outside the boundaries of the mapped area. All over the area these
basalt rocks were found to be horizontal or with a very
gentle local dip toward the south. In the northwest
part along the gravel road going to the Rio Vista Mine
just beyond the border of the mapped area there is an
intercalation of olivine basalt with Quaternary gravel,
which indicates that the age of these layers may be
Pliocene.

Quaternary gravels include all the flash-flood and
wash sediments of very recent age which are still being
deposited. They are very conspicuous along the Colorado
River and where drainage channels join that river. These
alluvial deposits have a considerable thickness in some
places.

C. Petrography

A total of 26 thin sections were studied under the
microscope. The goal of this study was determination of
the mineral composition of the main rock units and of
their degree of metamorphism. Information was sought
on the origin of the metamorphic rocks and the nature and
extent of the mineral alteration due to ore deposition.

1. Calc-Silicate Rocks and Marble Unit

The marbles were found to be impure with up to 40
percent quartz in some cases. Where this high value was
reached the rocks were named calc-silicates. In other cases the marbles had a low content of quartz. The general mineral composition of the calc-silicates is calcite, quartz, muscovite, feldspar, tourmaline, zircon, biotite, and sericite. The alteration seems to be very important, especially epidotization which is quite extensive together with introduction of calcite and hematite. All three appear to be introduced by a hydrothermal source. The epidote is common as a replacement of pre-existent minerals such as feldspar. It appears to have a high content of manganese as shown by its color. Hematite and calcite are most conspicuous in veins. The most common feature is granoblastic. Another possible origin for the alteration products is the breakdown of minerals that have Al, Ca, Fe, and Mn in their structures (such as biotite, muscovite). As a result of regional metamorphism they were spread through the metamorphosed rocks. This might suggest a syngenetic origin for the iron mineralization, but this seems unlikely because of the close association of copper and iron mineralization. Iron mineralization occurs also in unmetamorphosed rocks.
2. Gneiss

The main minerals of this rock are albite, microcline, quartz, biotite, rounded zircon, tourmaline, apatite, and garnet. Alteration products are epidote, calcite, and chlorite. The hematite appears to be an original mineral and usually is parallel to the foliation. The epidote alteration is very extensive. The presence of rounded zircon and hematite parallel to the foliation suggests a sedimentary origin for the gneiss with the original rock an arkose sandstone. The more common textures are mylonitic and granoblastic. The gneiss samples coming from the graben structure in the central part of the area show a very mylonitic texture and the epidote alteration seems more common. This may be because of the presence of fractures which would allow more hydrothermal activity. The matrix is usually a recrystallized mosaic of quartz and feldspar. In other cases a melanocratic matrix is present.

The gneiss samples from the two pre-metamorphic intrusives show a mineralogy of albite, microcline, quartz, muscovite, biotite, apatite, and garnet. The alteration is quite extensive. Here hematite appears most commonly as veins, and epidote replaces other minerals. The epidote
has a bluish color in all the places where it was found indicating a high manganese content. Thin veins of manganese minerals were found in this old intrusion. Not too much can be said about the petrographic differences between the igneous gneiss and the sedimentary gneiss.

3. Basic Dikes

The main minerals of these rocks are andesine (50 percent), hornblende (42 percent), hematite, magnetite, and only 5 percent quartz. Alteration includes sericitization of feldspar, chloritization of hornblende, replacement by epidote, and introduction of calcite veins. The schistosity is defined by prismatic orientation of hornblende crystals.

4. Mylonite Zones

These rocks seem to occur as dikes in some places and as sills in others. The main minerals are quartz (50 percent) and feldspar (35 percent) with lesser sericite and muscovite. The main characteristic of the minerals is their mylonitic texture. Large porphyroblasts of quartz and feldspar are growing at the expense of an extremely granulated matrix. Sericite appears to be growing. There is some accessory calcite. The rock was called mylonitized-
quartz-feldspar rock. The igneous origin is very doubtful. These zones are probably the result of mechanical deformation along shear zones, with partial mobilization of quartz and feldspar.

A mylonitic schist was studied from the west part of the area. It is different in occurrence from the mylonite in the last paragraph. It occurs in a small strike-slip fault in the west part of the mapped area.

5. Metamorphosed Conglomerate and Schist

From the schist samples studied, the mineralogic composition was found to be albite, microcline, bands of calcite, muscovite, biotite, rounded zircon, and garnet. Opaque hematite and magnetite were found along the foliation planes. The matrix is mostly micaceous. The alteration products are epidote and clay minerals. Poikiloblastic inclusions and helicitic textures are common. A sedimentary origin for these rocks is obvious. They were impure shale and impure sandstone, now metamorphosed to greenschist facies.

6. Tertiary-Cretaceous Sediments (T.K.S.)

Only one section was studied. Seventy percent of the rock is quartz and 15-20 percent feldspar, which is altered
to clay minerals in most cases. Grains of epidote are common. The high percent of feldspar classifies this rock as arkose sandstone.

7. Andesite

Samples were studied from the Sue Mine area. Their mineral composition is feldspar (30 percent) and glassy material difficult to differentiate. Also found were chlorite alteration and introduction of hematite in veins. The rock is hemicrystalline with hypidiomorphic texture.

8. Tuffs and Basalt Flows

The samples collected of the badly weathered tuffs were not very good for thin section study. Only sericite, calcite, and hematite were identified. The remaining glassy material could not be identified. A basalt flow sample gave a very good thin section, with olivine (15 percent) and labradorite (40 percent) identified. The matrix is glassy and difficult to determine. Opaque hematite and magnetite altered to chlorite and limonite were noticed. Accessory calcite is common. The conspicuous textures are porphyroblastic and poikilitic. It was named an olivine-basalt.
CHAPTER IV

STRUCTURE OF THE AREA

The structural features of the mapped area consist of foliation in the metamorphic rocks, joints, folds, faulting, and unconformities. Structural disturbance in this area has been great and mineralization is associated with some of these features.

A. Foliation

Foliation is present in all of the metamorphic units, especially in the schist and gneiss where mica and chlorite are more abundant and their parallel arrangement helps to denote this feature. Foliation, which often displays a banded appearance on airphotos, can not be so distinguished in the gneiss due to loosening of bed rock by surface weathering. The trend of foliation in the gneiss varies radically within the space of several feet. This may be due to displacement by small faults combined with a profusion of fractures which are very common since the gneiss is the most brittle rock in the area. Although many measurements of foliation were made in the gneiss no broad structure could be worked out. The foliation is parallel to the bedding, which in the gneiss was measured
where changes of lithology were found. Greenschists were noted to be intercalated with the gneiss. This intercalation is repeated all over the area and it can not be confused with sills that are conspicuous too, because these sills have igneous textures. The trend of foliation is also parallel in the other metamorphic units. This might suggest a genetic relationship between the stress that originated the folding and that which caused the foliation.

B. Joints

Joints occur in all rock types and are conspicuous throughout the area. The most prominent joints are the columnar type in the basalt. These are tensional due to the cooling and solidification of the flow. Two main sets of jointing are present in the gneiss, one trending almost north, steeply dipping west, and another one trending north-west and with an average dip of 60 degrees north. The north-south set may be tensional because they are parallel to a big tensional fault that crosses the western part of the area.

C. Folds and Faults

Folding and faulting are discussed here under the same subtitle because of the genetic relation between them. There
are two anticlines, one in the central zone and another in the eastern part of the area (Plate I). Both trend N80E. The south limbs of both of them are almost completely covered by basalt flows which makes it harder to understand some relations. They are also separated by unconformable beds of Tertiary–Cretaceous sediments (T.K.S.) and basalt which make it difficult to see what the relation is between the two anticlines. The central fold and the Tertiary–Cretaceous sediments are separated by a valley of Quaternary gravel that covers an old fault zone. This would explain the lack of continuation of the marbles toward the east. The faults have three main trends: N45E, N30W, and N-S.

It is necessary to assume a certain direction of the stress causing the faulting and folding of the area in order to explain the genesis of the structures. A northwest-southeast horizontal compression is assumed to be responsible for the folds trending N80E perpendicular to the assumed stress (Fig. 5). This developed a shear pattern running almost north-south and represented by a number of shear faults and mylonite-like dikes trending in this direction in the gneissic section. Perpendicular to this pattern and almost 45 degrees from the compression direction there is another shear fracture zone, almost east-west. This is
Fig. 5. Diagram of Assumed Stresses
represented by weak areas where a series of basic dikes and mylonite zones occur. Parallel to the axis of the folds and perpendicular to the compression stress there is a high-angle thrust fault in the eastern part of the area where the north active block moved southward over marble beds.

On the nose of the central anticline, parallel to the compression direction and perpendicular to the tension stress, there is a vertical gravity fault that dropped the nose of the anticline (Plate I). In the central part of the area there are two vertical faults that bound a graben wedge block of gneiss. These two vertical faults and the anticlines suggest that the easiest relief of the assumed stress was upward and almost east-west. The supposed compression originated the oldest structures in the area within the marbles and the gneiss.

A second group of structures was derived later, after the regional metamorphism, since these new features affected the non-metamorphic reddish conglomerate and sandstone of Tertiary-Cretaceous age. To this group belongs a series of faults in the western part of the area. One of these is a contact, high-angle thrust striking N30W and dipping 35 degrees west. It makes a contact between the gneiss
and the reddish brown conglomerate and sandstone (T.K.S.).
Toward the south is a higher-angle reverse fault. Parallel to this fault there is another reverse fault that shows slickenslides in its hanging (andesitic) wall (Fig. 6). This structure is the main channel of mineralization at the Sue Mine. Perpendicular to the thrust there is a small strike-slip fault which is a characteristic feature in a thrusting area. All these reverse faults and thrusts are perpendicular to an assumed new horizontal compression trending north-east which was responsible for this faulting and for the nappe of marble sitting on the top of the Tertiary-Cretaceous conglomerate and sandstone in the northwest corner of the area (Fig. 7). It was carried from the southwest. The same origin holds true for the shear zones along which some mylonite-like dikes and basic dikes intruded. One of these shear zones is north-south and the other is east-west, both about 45 degrees to the compression direction.

Although the mylonite zone can be explained by either one of these two compressions it may be that during formation of the first set of structures they intruded as aplites, then during the second deformation shearing occurred along them. This would explain why they are so mylonitized today.
Figure 6. Reverse(?)/fault at Sue Mine.
Figure 7. Nappe of marble over Tertiary-Cretaceous sediments.
D. Structure and Mineralization

There is also a group of small faults and shears of insignificant geographic extension and of probably small displacement. Some of them are localized close to the nose of the anticline, which carries mineralization in some cases. The Rico Mine is on the axis of the central anticline. A normal fault located north-east of the main Rico tunnel has mineralization.

The Rio Vista Mine is structurally on the nose of the anticline. The mineralization is mostly in two small normal faults. In the gneissic section two of the north-south shear zones carry mineralization. The Carnation Mine has its main mineralization in a bedding plane forming a bedding-type replacement.

So far no mineralization has been found related to any of the regional faults that exist through the area. But it can be said that mineralization and structure are related since mineralization is associated with open space features. However, there is no special trending of those faults that carry the most mineralization. It occurs in the whole section from the oldest marbles and gneiss to the youngest conglomerate and sandstone of Tertiary-Cretaceous age. Whenever mineralization is found there
is a shear or fracture that justifies its presence. It can be bedding in some cases. For this reason a large number of mineralized zones occur in the small mapped area, which is characterized by intense fracturing.
A. Mineralization

Two types of ore deposits are conspicuous in the mapped area: 1) bedding and vein replacement in marble and calc-silicates, and 2) fissure filling in small faults, shear fractures and breccia. The second type seems to be predominant. The mineral assemblage is simple. Hematite is the iron mineral, and chrysocolla, azurite, and malachite are the copper minerals. In the Sue Mine and the Rico Mine traces of chalcopyrite were found. In a sample submitted by Mr. Richard Albright, from ground water level in the Sue Mine, chalcopyrite was found replaced by supergene bornite, covellite, and chalcocite. Hematite looks younger than the sulfide in this sample. The mineralization in this ore seems to follow a northeast trend which may be due to a similar trend of carbonate rocks. These rocks are favorable for replacement by iron mineralization and are the host rock for many ore deposits, although mineralization is spread through the whole section regardless of lithology. The mineralization is not related to any particular trend of faulting but it is related to local faults and shear zones.
B. Main Occurrences

1. Carnation Mine

The ore has been mined from two main areas. The ore in one area came from an inclined shaft of about 40 degree slope, parallel to the bedding. The mineralization is of bedding-replacement type in carbonate rocks (Fig. 8). The other production came from another small shaft east of the first one where the host rock is quartzite and the mineralization is a fissure-filling type in brecciated quartzite. The elements of economic value are copper (chrysocolla, malachite, and azurite) and iron (hematite).

2. Eagle Mine

The mineralization here is in a shear zone in a gneiss lens within the calc-silicate section. The iron mineralization does not seem to be extensive. The copper mineralization is more abundant. The amount of silicification around the shaft, where there is a series of white quartz veins, is very prominent.

3. Well Mine

This mine belongs to the group of mineralized zones localized in young Tertiary-Cretaceous sediments. The mineralization is in shear zones and in sedimentary breccia
Figure 8. Mineralization at Rico Mine.
which offers good permeability for the ore-bearing fluids
to be precipitated.

4. Rico Mine

This mine is located on the axis of an
anticline (Plate I). The host rocks are marble and calc-
silicates. The main mineralization is bedding replacement
in the upper tunnel and in the lower tunnel vein replace­
ment along a small normal fault trending east-west and
dipping 40 degrees north. Northwest of this tunnel
there is a small normal fault which is mineralized also.
The ore production averaged 15 to 20 percent iron and
4 percent copper, and a small amount of gold was produced.

5. Billy Mack Mine

The mineralization is iron bedding replacement with
some oxides of copper represented by malachite and azurite
mainly. The iron appears to be more extensive than the
copper.

6. Rio Vista Mine

There are two areas included in this property, the
South Rio Vista Mine and the North Rio Vista Mine. The
main mineralization at the North Mine is vein replacement
and at the South Mine breccia filling in brecciated quartzite.
Structurally this zone is on the nose of an anticline, which is the reason for much small shearing and brecciation which controls the mineralization. The mineralization is similar to that of the Rico Mine. The grade in these mines was 9 to 10 percent copper and one ounce/ton gold (Osborne, 1964).

7. Sue Mine

The Sue Mine, the Well Mine, and a mineralized outcrop about half a mile from North Rio Vista Mine along a wash passing in front of that mine are the only mineralized zones in the young Tertiary-Cretaceous sediments and andesite. The author found that chalcopyrite is conspicuous in polished sections from the Sue Mine. In a sample submitted by Mr. Richard Albright, beautiful ring and veinlet replacement textures of chalcopyrite by bornite, covellite, and chalcocite were found. These are evidently of supergene origin. Veins of hematite cut across these sulfides. From this sample the iron mineralization appears to be younger than the sulfides, and the copper oxides of the oxidized zone are the youngest ores all through the area.

Chalcopyrite is the only primary sulfide found in samples of the area in which supergene bornite, covellite, and chalcocite were derived. These sulfides are the
original material from which the copper oxides formed. The gangue minerals are quartz, calcite, and barite at the Sue Mine.

The general sequence of mineralization derived from polished section studies seems to be:

chalcopyrite---
  bornite------
  covellite-----
  chalcocite----
  hematite---
  malachite----
  azurite------
  chrysocolla--

C. Ore Control

The main controls are structural and stratigraphic. Mineralization is related to a series of small faults, shear zones, and breccias. Generally it does not follow any particular trend of structures. In other words, the mineralization is related to small local features in each specific mine. Only in the Sue Mine is the mineralization in a somewhat more extensive normal fault. These small features are related to the general structure of the area since they are secondary features developed from the large ones. For instance, the small faulting in the North Rio Vista Mine belongs to the kind of structures expected in the nose of an anticline, and the faulting in the Rico
Mine is of the same origin, being due to compensation of the vertical release of the horizontal compression that originated the folding.

It has been said in the preceding pages that the iron mineralization is more extensive in the marble and calc-silicates due to the fact that carbonate rocks are more susceptible to replacement by the iron mineralization than are the siliceous sediments. Therefore, the carbonates provided a good stratigraphic control for the mineralization in the area. For the fissure-filling type of ore deposit there is not a specific horizon controlling the deposition. It depends upon the presence of fractures in the country rock.

D. Origin of Mineralization

A syngenetic origin for iron in this area could be due to iron released by metamorphism from magnetite, hematite, chlorite, biotite, and other minerals that have iron and other elements in their structure and are major constituents of the rock. The solutions would migrate through channels and precipitate where conditions were favorable along the fissures. This is difficult to postulate in the area since the metamorphism is of low grade (greenschist facies) and might not have reached the
necessary temperature to mobilize the iron content of the sediment. With respect to copper mineralization, which came from oxidation of sulfides, no trace of sulfides was found in the sections of the metamorphic rocks.

A second argument against a syngenetic origin is the fact that the mineralization is found in young unmetamorphosed Tertiary-Cretaceous sediments, in which the iron mineralization is younger than the sulfides. In other words there were two stages of mineralization, one of sulfides and one of iron. The two types are closely associated in the field and probably came from the same source.

An epigenetic origin seems more likely. Specular hematite, which is very conspicuous in the area, is a high temperature mineral related to intrusive rocks. These do not outcrop in the mapped area. This type of mineralization might be of the xenothermal type, a term introduced by Buddington (1935) for high-temperature ore deposits formed close to the surface where hydrothermal fluids have their origin from shallow-depth intrusions and where open fissure textures tend to predominate over replacement features. In this type of mineralization the host rock is cracked, sheared, and fractured, as is very common in the ore deposits of the thesis area.
The mineralization might be a mesothermal type of deposit where the source of the hydrothermal fluids is difficult to determine due to the lack of an intrusive in the area.

A third possibility would have the hematite belong to an exceptional type noted by Park (1963) in Mountain Home, west of Hanover, New Mexico. Park states that "plates of specularite were found in limestone above the water table. They are not found at depth and are thought to be of supergene origin."
CHAPTER VI

SUMMARY AND CONCLUSIONS

The oldest rocks in the area are the calc-silicates and marbles since they form the core of the anticlines. These metamorphic units include a unit consisting of an interlayering of calc-silicate rocks, local marbles, greenschist, quartz feldspathic schist, and quartzite that appears in the upper part of the section (cross section AA', Plate I). This unit passes transitionally into the gneiss unit since intercalation of gneiss and marbles is observed in the east part of the area (cross section CC', Plate I).

Several pieces of evidence prove that the gneisses are metamorphosed sediments. For example: (a) the intercalation of gneiss and marbles (Section CC', Plate I); (b) the absence of polysynthetic twins in feldspars which would be expected from original igneous rocks; (c) the intercalation of greenschist and gneiss, which can be followed for almost 100 feet in the field; (d) relic bedding can be observed locally between gneiss and greenschist; (e) the lack of homogeneous composition from place to place within a few feet; (f) the lack
of zoning in feldspar in thin section studies; (g) the heavy minerals, zircon, and opaque minerals are parallel to the foliation as seen in thin section; (h) the roundness of the zircon grains.

Gneisses of igneous origin were identified in the area (Plate I). They represent two small pre-metamorphic granitic intrusions. The major evidence for this origin is their rounded shape and their homogeneity.

A third metamorphic unit was identified in the south corner of the mapped area. It consists of metamorphic conglomerate, quartz-feldspathic schist, and quartzite. Their field differentiation with respect to the calc-silicate and marble is based on the lack of marble, the presence of conglomerate, and the fact that the quartzite is somewhat more impure. This unit's field relationship with the other units could not be determined due to covering of the rock by Quaternary sediments and basalt flow. With this unit, the gneiss, and the calc-silicate unit, a total of three different metamorphic rock units were identified.

Unconformable in some places, and in fault relationship in others, appear the unmetamorphosed conglomerate, sandstone, and shale of presumed Tertiary-Cretaceous.
The composition and the red color point out the near-shore to continental environment of these sediments. The poor sorting and angular shape of their major constituents show that they were deposited under conditions of fast deposition and fast subsidence characteristic of basin and range basins.

Andesite was also identified with the T.K.S. at the Sue Mine where their contact relationship is a fault, and along Highway 95 where the andesite appears intercalated with the T.K.S. sediments. This andesite may be older than the basalt flows since there is an intercalation with T.K.S. rocks.

Unconformable upon the older rocks of the mapped area lie a series of intercalated tuffs, olivine-basalt flows, and ash beds. They cover much of the southeast part of the area and thicken outside of the mapped area in a southeasterly direction.

The structure of the area is represented by two major anticlines, one in the central and west part of the area, and the other in the east part with calc-silicate rocks and marble in the core passing transitionally to gneiss. A northwest-southeast horizontal compression stress is responsible for the oldest structural features of the
area, such as the anticlines, the thrust fault in the east part, the vertical faults in the central part of the area, and the gravity or vertical fault in the western part. A second, younger horizontal compression trending northeast-southwest determined the younger structures of the area such as the contact fault between T.K.S. sediments and older rocks in the western part of the area, the nappe of marble in the northwest corner of the area, and some shear zones in the gneiss.

Mineralization was widespread in this area. It is partly represented by copper carbonates resulting from oxidation of sulfides. Iron mineralization in the form of hematite followed sulfide formation and preceded their oxidation. In general, the mineralization is related to local fracturing rather than regional structure. The main mineralization occurs where open spaces were available to ore solutions. The limestones were a good stratigraphic control for bedding and vein types of iron deposits. However, mineralization is found throughout the whole stratigraphic section regardless of the lithology.

An epigenetic hydrothermal origin for the ores seems to be likely since there is no trace of copper in the non-mineralized rocks of the area. Iron and copper mineralization
are closely related. Because of the presence of hematite, a high temperature mineral, and traces of tungsten mineralization in some places, a tentative xenothermal classification of the ores was made.
BIBLIOGRAPHY


VITA

Elias Zambrano was born June 16, 1936 in Anzoategui, Estado Lara, Venezuela. He received his high school education from Liceo "Lisandro Alvarado" and Colegio "La Salle" in Barquisimeto, Venezuela, graduating in 1956. He entered the Universidad Central de Venezuela Caracas where he received his B.S. in Geology in 1961. He was then employed by the Direccion de Geologia, Ministerio de Minas e Hidrocarburos in Caracas. In 1962 he was married to Hilda Hidalgo de Zambrano. They are the parents of a son. In 1964 he was selected by his employer to be sent to the United States of America for graduate work, going first to the English Language Institute, University of Michigan, Ann Arbor, Michigan. He then entered the University of Missouri at Rolla in the spring semester of 1964.

His professional interest lies in regional geology related to mineral exploration.