GEOLOGY OF THE FOOTWALL FORMATIONS OF THE VETA MADRE, GUANAJUATO MINING DISTRICT, GUANAJUATO, MEXICO

by

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STATEMENT BY AUTHOR

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ABSTRACT

The area studied for this report contains the following rock units: (1) Mesozoic phyllites and limestones, (2) Cenozoic(?) andesite, (3) Cenozoic(?) granite and subsequent quartz diorite intrusions, and (4) Eocene or Oligocene Red Conglomerate.

Guanajuato has yielded about half a billion dollars in silver values during its four centuries of production. The distribution of silver sulfide and sulfosalt minerals is seemingly controlled by structural features.

The probable existence of a small anticline has been established. The trend of the horizontal projection of the line of intersection between the Veta Madre fault and the axis of this anticline strikes toward the principal shaft of La Valenciana mine. It is suggested this intersection may be an ore control and may account for the huge production of this
The principal ore control in the Guanajuato Mining District appears to be the deflection of the Veta Madre that is caused by variations in the relative competency of the fractured rock units. Oblique and/or rotational movement along the fault surface has produced wide zones of shattering.
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<td>1. Geologic map of a portion of the Guanajuato mining district</td>
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Guanajuato is famous for the great amount of silver mined during its four centuries of activity. The mineros have added to this fame by sinking the largest diameter shafts in the world. The La Valenciana is typical of these gigantic shafts. Baron von Humboldt visited Guanajuato in 1803. He described this 1,600-foot vertical shaft, with its 32-foot diameter, as one of the greatest engineering works in the history of mining. These immense shafts were designed to accommodate up to eight hauling cables to hoist ore and water in leather buckets. The large I-beams have been recently installed in preparation for an attempt to unwater the mine.
INTRODUCTION

Location

Part of the area embraced in this report is located within the city limits of Guanajuato, State of Guanajuato, Mexico. The paved highway from Guanajuato to Dolores Hidalgo passes through the center of the area mapped for this thesis; hence the area is readily accessible.

Design of Investigation

Guanajuato is an active mining district employing about 1,200 men annually in the mines, although production is now limited to approximately 3 million ounces of silver annually. This thesis was designed to establish surface geological control along the portion of the Veta Madre that has been the most productive. The hanging wall has been mapped recently by Edwards (1955), but the footwall formations have never been mapped in detail. Prior investigations have, in general, neglected local structure. This study has attempted to define the structure and the character of the footwall formations in hopes that these data may lead to ore discovery in the mines of Guanajuato.
Figure I.—State of Guanajuato, Mexico
Field and Laboratory Techniques

Fieldwork was conducted during the months of July and August 1963. The author mapped the geology directly upon a high-altitude photograph taken in 1959 by Compania Mexicana Aerofoto, S. A. The photograph that served as a base map was enlarged from its original scale of 1:20,000 to 1:5,000 by the same company in Mexico City. The scale of the photograph was checked by comparing two known points on the enlarged contact print with the same two points located on a triangulation survey completed by H. T. Mapes in 1915 for the Guanajuato Reduction and Mines Company. The distance between the two points according to Mapes' survey is 2,358.892 meters and 2,350.0 meters as measured on the photograph—an error of about 9 meters caused by variation in topographic relief, inclination of the optical axis of the camera, or distortion during the enlargement process.

Great care was taken to walk along each contact of rock types so the geology could be accurately plotted on the photograph. The geology was transferred by direct tracing from the enlarged contact print to the final map. The topographic contour lines were traced from a plane-table map made by J. Baltierra G. and F. Rendon in 1946.

The laboratory work was performed at the University of Arizona. Three polished sections of ores were made, and 46 thin sections were prepared from surface rocks obtained from both the hanging and
footwall of the Veta Madre fault. Microscopic study of these sections was used for classification, alteration, metamorphism, and paragenetic studies. No petrofabric determinations were attempted, but the author feels such a study might yield kinematic data that might be used to aid in visualization of the structural evolution of this area. Twenty-one photomicrographs were taken of thin sections, and a few of these are included in this report.

Pollen and spore analyses were conducted in the Geochronology Laboratories, University of Arizona, on the Mesozoic and Cenozoic sedimentary rocks. Fifteen slides were prepared and closely scrutinized for pollen and spores.

A mineral specimen containing quartz crystals overgrown with fluorite cubes was sent to the U.S. Geological Survey Laboratory in Washington, D. C. This large specimen, weighing about 4 pounds, was presented to the author by Alfredo Terrazas and Humberto Bastin. They said the specimen was found on the 160-meter level in the footwall of the Tepeyac mine. Bastin observed there was considerable ore surrounding the specimen when it was discovered. Victor Hoffman, a graduate student at the University of Arizona, noticed unusual growths over the fluorite cubes that could not be identified by inspection. He offered to run X-ray analysis to determine the mineral, but he found that upon breaking open one of the unknown crystals fluid escaped; hence, Dr. S. Titley suggested that an analysis of the liquid and gas might provide
the composition of the ore-bearing solutions at the time of deposition.
The analysis is not yet available.

**Topography, Drainage, and Climate**

Figure 2 illustrates the topography of this region, and the flora exemplified reflects the climatic conditions that prevail in this section of the country.

The relief within the area of study is moderate, amounting to about 400 meters. The drainage pattern on the east side of Veta Madre is a crude trellis pattern probably developed due to structural complexities and various rock types present. The drainage motif on the west side of Veta Madre has a closer affinity to the pattern described by dendritic drainage than any other type and may result from greater uniformity in rock resistance to erosion.

**Acknowledgments**

The author is pleased to acknowledge the fine reception extended to him by Ing. Ruben Pesquera Velazquez, Subgerente de Exploracion, Consejo de Recursos Naturales No Renovables, and other members of his staff in Mexico City.

In Guanajuato, engineers Jose Echegoyen Sanchez, Jose Ramirez Rubalcaba, and Saul Romero Martinez were particularly congenial. They shared their office and provided the writer with office facilities. Their
FIGURE 2

Panoramic view of a portion of the Guanajuato mining district. The city of Guanajuato can be seen in the middle background. The large stone wall, fashioned after the crown of the King of Spain, surrounds the general shaft of La Valenciana mine (see frontispiece). The observer is looking south. Red Conglomerate and granite rocks are between the city and the observer. These two rock types exhibit a similar rounded topographic expression. The city limits define the southern boundary of the mapped area. Various types of flora indicate climatic conditions.
secretary, Margarita Sanchez Escoto, was very helpful in compiling various sources of information.

Ing. Alfredo Terrazas, Gerente of the Cooperativa Santa Fe de Guanajuato, kindly permitted the author access to the mining complex and was very generous with information regarding the mines and geology of Guanajuato.

Ing. Eduardo Meave provided the author with any assistance requested, and his help and cooperation are greatly appreciated.

At the University of Arizona, the following graduate students rendered aid that expedited the completion of this work: Victor Hoffman prepared some of the thin sections; Richard D. Champney took all of the photomicrographs; David Peabody, Peter Mehringer, and Richard Hevly—all of the Geochronology Laboratories—instructed the author in techniques of spore analysis. The author is much obliged to these students.


Thanks is due to T. W. Parker, Director of the Special Master's Program sponsored by the Ford Foundation, for the expense money allotted to the author to compensate him for part of the expenses incurred in this study.
The enthusiastic support of Dr. S. R. Titley is greatly appreciated. He is responsible for sending the fluorite sample to Washington, D. C. for analysis.

The writer is delighted to express his appreciation to his thesis director, Professor Willard C. Lacy. His help was indispensable, his ideas were utilized, and his guidance accepted.

Mrs. Carol L. Jenkins typed the manuscript.

Previous Work

The major outlines of the geology in the area studied were determined by Wandke and Martinez (1928). Their report covered the general geology of the Guanajuato mining district with emphasis on economic geology. Prior to and later than this report, numerous articles by various authors were written regarding different aspects of this district, but most of these papers were concerned with mine promotion and expected results from forthcoming projects. In 1950, Wilson, Milton, and Houston wrote a report on "A Mineralogical Study of the Guanajuato, Mexico, Silver-Gold Ores." Edwards (1955) has written a paper on the red conglomerates of Guanajuato. Wisser (1960) dedicated several pages to this area based on the report of Wandke and Martinez plus unpublished reports and field notes of his own observations. Guiza (1949) performed a general geological study of the Guanajuato mining district.
GENERAL GEOLOGY, GUANAJUATO MINING DISTRICT

Regional Geologic Setting

According to Wisser (1960, p. 77) the axis of a large geanticline cuts through the Guanajuato area. He has termed this structure the Occidental geanticline, a positive and intermittently active tectonic element with a history dating from middle Mesozoic time. Wisser has suggested the crystalline basement may lie at great depth in this area. The author does not share this view. Wandke and Martinez (1928) describe the geologic environment of the Sierra of Guanajuato as a large anticline that has been block faulted with a trend to the northwest. Erosion has carved the faulted anticline into a series of peaks that are surrounded by large valleys that are characteristic of the great dissected plateaus of Mexico. The Sierra of Guanajuato is only one of a series of parallel folds that have been developed in the Mesozoic sediments. The accumulation of the folded Mesozoic sediments and the thick pile of Tertiary lavas has obscured many of the prominent structures and covered the Paleozoic rocks. All the tectonic features observed along the Occidental geanticline and related parallel folds can be best explained by vertical uplift resulting in normal faults, thrusts, and
gravitational gliding tectonics (Wisser, 1957, p. 62).

There may be a link between the northwest-trending Gulf of California, which follows a geosuture shown by Hamilton (1961) to be a continuation of the San Andreas fault, and the parallel tectonic structures in Mexico as delineated by Wisser (1960). Wisser has outlined a number of ore districts in relation to tectonic features which substantiates that a remarkably close relationship exists in parts of Mexico between metallogenetic belts and lineament tectonics.

Local Geologic Setting

The oldest rocks in the Guanajuato area are marine limestones and shales that have been altered to slates and phyllites. The limestone still retains much of the original depositional characteristics, although it shows some signs of metamorphism. The phyllite and limestone (apparently cyclic) sequence has been identified as the Esperanza Formation by Echegoyen (1963, personal communication). The Red Conglomerate is the only other sedimentary rock located within the area embraced by this report. Edwards (1955) reports the Red Conglomerate overlies the Esperanza Formation unconformably. The author cannot verify this observation, as the two units in the area studied were separated by the Veta Madre fault. The contact on the hanging wall is hidden under the Red Conglomerate—not even the 2,000-foot Nueva Luz shaft reaches the underlying Mesozoic sediments. The Red Conglomerate
has been eroded completely away from the footwall sector of the Veta Madre, leaving only the slate, phyllite, limestone, and igneous rocks exposed in the footwall sector of the Veta Madre fault.

Igneous rocks include hypabyssal (dikes, sills) and plutonic types. Quartz diorite dikes cut the large granite, quartz monzonite intrusives, and a quartz felsite sill is well exposed in the Red Conglomerate. Hypabyssal andesite rocks intrude the Mesozoic sediments. The andesites are tabular-like bodies that have a large areal dimension as compared to their thickness, as revealed in the mine workings.

Alteration is most pronounced several hundred yards east of the general shaft of La Valenciana and consists predominantly of silification in this area. It is probably genetically associated with the quartz felsite sill (see pl. 1) that has invaded the Red Conglomerate.
ROCK UNITS

Phyllite

The most abundant rock in the footwall of the Veta Madre is phyllite, often referred to locally as "lutite." The field determination of these rocks was based on the lustrous sheen given off by the mica, although segregation banding was not evident. Microscopic study of thin sections confirms the megascopic determination (fig. 3).

The phyllite was originally a claystone, for over two-thirds of the original mud fraction contained clay-sized grains. The grains were derived from terrigenous components (Folk's classification) that were transported into the site of deposition as solids. Most of the quartz appeared to be microcrystalline (less than 20 microns) with subordinate amounts of megacrystalline quartz present. No chalcedonic quartz was observed. Most of the quartz grains were so small no genetic (Krynine's classification) or empirical (Folk's classification) classification could be assigned. A few of the megacrystalline grains had straight extinction and microlites, indicating common plutonic rocks as their origin. There were not sufficient megacrystalline grains to provide a statistical basis to be certain of the genetic classification in order to be able to conclude about the provenance of the sediments.
FIGURE 3

A.
Muscovite-chlorite-quartz phyllite. Note well-defined segregation banding that is characteristic of schists, but minerals cannot be determined megascopically; hence the rock is a phyllite. The main rock cleavage (horizontal) is crossed by a later strain-slip cleavage (near vertical) caused by microfolding. A little sericite is present. Plain polarized light, X 100.

B.
Chlorite-quartz phyllite. All minerals throughout rock are strained. The component of slip lying in the plane of the section can be inferred. It was a late development that post-dates all mineralization with the exception of pyrite that is found in the phyllites lying close to the Veta Madre.
Plain polarized light, X 32.
No fossils were found, and analyses for pollen and spores in two phyllite specimens were unsuccessful.

The secondary cleavage developed from flow cleavage parallel to the bedding. The author concludes this to be the case, since the cleavage in the phyllite is everywhere conformable with the bedding in the contiguous limestone, and the secondary foliation of the phyllite has the same attitude as the limestone sequence. There is, in addition, a later cleavage imposed on the main bedding cleavage that caused small microfolding. This cleavage is almost perpendicular (fig. 3) to the bedding cleavage.

The original sequence of claystone alternating with limestone provides an interesting situation—why is the claystone metamorphosed to a phyllite and the limestone which is sandwiched within the phyllite relatively unaltered? De Sitter (1956, p. 79) has explained that competency of rocks is a measure of their physical properties, and that for a given stress condition the incompetent rocks have a lower elasticity limit and a lower viscosity. For example, according to De Sitter, at a depth of 1 kilometer plastic flow would be expected in shales but only elastico-viscous flow in limestones and sandstones. This explanation by De Sitter may reconcile the apparent disharmony.

No stratigraphic measurement could be made of the phyllite sequence since the deepest mines have not penetrated this unit.

Within the phyllite and exposed at various places along Veta
Madre is a black phyllite which is locally termed the Black Shale. This phyllite is barren of fossils. The author could not determine by thin-section study the nature of the dark-gray pigment (fig. 4). According to Krumbein and Sloss (1963, p. 123), the black pigment is generally either carbonaceous matter derived from organic tissues that were deposited with the sediment or finely divided iron sulfide. Black shales were once thought to be indicators of a deep, stagnant environment below wave base, but some investigators argue extremely shallow water is more feasible (Conant, 1953). Hence, the true conditions of the environment of deposition have not been established. The author is inclined to believe the pigment is organic matter. A sample of the black phyllite was subjected to decomposition by application of concentrated hydrochloric and hydrofluoric acid. The breakdown of the rock yielded a black residue that appeared, when viewed under the microscope, to be a mixture of petroleum hydrocarbons and clastic components. The black residue gave off a blue fluorescence when exposed to an ultraviolet light (shortwave length of 2,537 Angstrom units) that is characteristic of petroleum hydrocarbons. The writer subjected all coal specimens in the collection at the University of Arizona to ultraviolet light and none responded. This is not a conclusive test, but it is probable that coal hydrocarbons are not fluorescent. If this is the case, then the conclusions from microscopic observation coupled with the blue fluorescence given off by the black residue indicate it contains
Black phyllite (locally called "Black Shale") lacks the well-defined segregation banding and rock cleavage displayed by other phyllites in the sequence. The presence of petroleum hydrocarbons accounts for the black pigment and variation in fabric usually ascribed to phyllites. Microcrystalline quartz is the only mineral identified among the clastic components. The large white blobs are Lakeside 7 cement. Plain polarized light, X 32.
petroleum hydrocarbons. This tends to confirm the author's statement that the sediments were deposited in a marine environment. It is highly probable that the environment limits had a range of 0.0 to -0.1 Eh and 5.0 to 7.0 pH (Krumbein and Sloss, 1963)—a reducing environment.

The Esperanza Formation, of which the phyllite is a member, has been dated as Jurassic. Edwards (1955, p. 157) reports a few marine fossils were found in limestone cobbles in the Red Conglomerate. The fossils were deformed, but they retained sufficient morphological features to date the limestone as Jurassic.

Organic debris (other than petroleum hydrocarbons) was disseminated throughout the black residue. The debris appeared to be pollen remnants that had disintegrated (Kremp, personal communication). Unfortunately, the pollen could not be recognized. The writer had hoped to establish the age of these rocks on the basis of the recognition of various spores and pollen.

Figure 4 illustrates the fabric of the black phyllite. The rock is composed mainly of microcrystalline quartz and other unidentified clastic components. There is an obvious lack of segregation banding and rock cleavage so evident in the photomicrographs of figure 3; nevertheless, from a megascopic examination the rock should be classified as a slate or phyllite due to its cleavage and black sheen. It is called a phyllite in this report.
Limestone

The limestone members of the Esperanza Formation are dark blue gray (on a freshly broken surface), thin bedded, and fine grained. The member mapped (pl. 1) on the surface is about 50 meters thick. This member is sandwiched in between the phyllite sequence (thickness unknown). Thinner members (perhaps it would be better to describe these members as lentils, as it is probable these beds pinch out in a short distance) have been recognized in the Cata mine near the cross-cut Villaseca and elsewhere. The vertical sections shown on plate 1 describe the approximate projections of the limestone units within the Esperanza Formation. Detailed subsurface geological mapping will reveal facies variation within the phyllite sequence which will account for the limestone members, tongues, and lentils.

Thin-section study disclosed the rock to be composed mostly of microcrystalline calcite (grains 1 to 5 microns in diameter) with numerous grains of sparry calcite (crystals 10 microns or more in diameter) that probably were formed by recrystallization of the microcrystalline grains. Small amounts of clay-sized components are disseminated throughout the rock. Most of these components appeared to be quartz. Folk's classification was used to describe these rocks as a terrigenous clayey, spariticmicrite limestone.

Folk (1961, p. 142) postulates the environment characteristics
of microcrystalline carbonate rocks as follows: "... implies both a rapid rate of precipitation of microcrystalline ooze together with the lack of strong currents. Texturally they correspond with the claystones among the terrigenous rocks." If a micritic limestone is interbedded with fine-grained sediments, such as shale, then this is evidence that the water was relatively deep—perhaps a large lagoon was the environment of deposition. The climate of the region must have been humid to account for the preponderance of clay-sized particles in the Esperanza Formation. The presence of micritic limestone members within the phyllite sequence indicates times of less rainfall, which would account for the lesser amounts of clay introduced, thereby permitting the accumulation of the microcrystalline calcite ooze.

Folk (1961, p. 150) reports that the significance of color in limestones is not well known. Many limestones from deep geosynclines are dark colored, as are many shallow lagoonal limestones.

The Alizarin Red S staining technique was employed to test for the presence of dolomite. The check indicated that there is no dolomite in the rock.

No megafossils or microfossils were found. Edwards (1955) mentions that a few silicified corals and broken fragments from pelecypods, cephalopods, and bryozoa were found in several cobbles within the younger Red Conglomerate. Nine different micritic limestone rocks were decomposed by the Mehringer process (a technique utilizing various
acids extended over about a 60-hour period), and only organic fragments were found. Dr. Kremp believes the fragments were from pollen or spores, but none could be classified; hence no age for these rocks could be determined by this process.

The Esperanza Formation has been folded and subjected to stresses that have caused a weak secondary foliation discernible only by thin section.

The micritic limestone is resistant to erosion and irregularly caps hills and ridges.

**Andesite**

The andesite was described in the field as a greenish- to bluish-gray felsite. A study of various thin sections showed the felsite to have zoned plagioclase. Most of the plagioclase was andesine with a composition of $\text{An}_{35}$, as determined by the Michel-Levy method. Some of the thin sections contained less than 1 percent visible quartz, whereas some contained about 10 percent quartz. The andesine content and general deficiency of quartz establish the felsite to be an andesite. In many of the thin sections the groundmass was so fine grained that identification of the constituents was impossible. Some of the samples had phenocrysts of feldspar that were quite large and well developed, and others lacked phenocrysts entirely. Metacrysts of pyrite are conspicuous in the proximity of the Veta Madre. At a distance of about 900
Andesite, 450 meters east of Veta Madre. The quartz crystal is a xenolith. The andesite crystallized in a hypabyssal environment forming sill-like bodies. Note the small cubes of pyrite in and around the quartz fragment. The pyrite crystals are known to increase in size the closer they are found to Veta Madre. Plain polarized light, X 100.
meters from the vein no pyrite was evident; hence it appears that hydrothermal alteration was responsible for the formation of pyrite. The andesite is not altered sufficiently to call it a propylite, for there has been only minor development of chlorite, epidote, calcite, and quartz minerals.

The average andesite is comprised of about 35 percent mafic minerals (Grout, 1932, p. 88). Upon decomposition of these minerals sufficient iron was released to unite with sulfur to form the replacement pyrite. The sulfur is believed to have been transported by hydrothermal fluids that have gained access to the rocks by the numerous fractures associated with the large Veta Madre fault. Diffusion of ions outward from the fractures (Lindgren, 1933, p. 176) may have been an important mechanism of the replacement process.

Figure 5 depicts the large quartz fragments that are occasionally seen in the andesite. Apparently these xenoliths were picked up by the andesite as it intruded the overlying sediments. The quantity of xenoliths digested may account for the variation in the texture of the andesite.

The author at first believed the andesite represented the margin of a plutonic mass that had been subjected to relatively rapid cooling to account for the aphanitic character of the rock; however, subsequent visitation to the Rayas, Guadalupe, and Cata mines established that the andesite formed sill-like bodies within the Esperanza Formation. The
environment of these bodies can be described as hypabyssal. The andesite had risen from depth as a magma, intruded the Mesozoic sediments, and solidified in sills of varying dimensions.

The joint pattern in the andesite cannot be used to interpret the dynamics of the area (fig. 6). The pattern displayed by fracturing could be caused by almost any stress application (Mayo, personal communication). No connection can be linked between stress distribution and strain pattern because the joints in the area were not mapped in sufficient detail to provide a basis for any geometrical relationships.

Granite

The medium-grained granite was formed from a differentiating magma. Boulder-sized cognate xenoliths of andesite surrounded by granite are to be seen on the south side of the highway from Guanajuato to Dolores Hidalgo, 1.8 kilometers east of the Esperanza mine and directly above the Esperanza reservoir. The xenoliths of andesite indicate the granite is younger than the andesite. It is probable that the andesite, granite, and late quartz diorite dikes are all genetically related, as suggested by similarity of plagioclase composition. The anorthite composition of the plagioclase in the three igneous rocks ranges from An_{21-38}.

Thin-section study revealed gradation within the granite toward a quartz monzonite rock composition, but in general the rock is a granite.
Joint pattern in andesite. Brunton compass is oriented true north. The joints are classified according to their relationship with the planar flow structure. Cross joints are (Q) perpendicular to the flow lines. These are tension joints. Longitudinal joints (S) strike parallel to the flow lines. Both (S) and (Q) joints have near-vertical dips. The motif described by these joints cannot be used to interpret the dynamics involved in their creation.
Deuteric alteration was not recognized; however, the granite has been hydrothermally altered. The feldspars are partially altered to clay minerals and biotite has altered to chlorite and epidote. A few opaque minerals could not be identified.

The granite has been intruded by numerous dikes of quartz diorite. Field relationships could not be used to determine whether the granite had intruded the quartz diorite or vice versa. The distinction between the granite and quartz diorite was based on the type and quantity of feldspar present—greater than two-thirds of the feldspar content in a granite is orthoclase, whereas a quartz diorite carries greater than 90 percent of the feldspar as plagioclase.

Microscopic study of the two units showed the granite to be highly altered in comparison to the quartz diorite, and since both of these rocks contain essentially equivalent mineral components in different ratios, the degree of alteration might be used to establish the granite as the oldest intrusion. This conclusion conflicts with Wandke and Martinez's (1928, p. 12) statement that the granite is the youngest intrusion. The author is cognizant that the usual sequence of differentiation would cause the investigator to assume the more basic rock to be the oldest. Figure 7 exhibits the difference in alteration between the granite and the hornblende quartz diorite.

The author has included the granite within the rocks of Cenozoic age. This assumption cannot be confirmed, since the granite could have
FIGURE 7

Granite in photomicrograph A shows much greater hydrothermal alteration than the hornblende quartz diorite in B.

A.

Hydrothermally altered granite. The fabric of the rock is partly destroyed. The feldspars are altered to clay minerals. Biotite has been altered to chlorite and epidote. There are a few unidentified opaques. Plain polarized light, X 100.

B.

Hornblende quartz diorite. The feldspar crystal located in the center is relatively unaltered. The plagioclase is andesine, An$_{30-38}$. Incipient development of clay minerals observed in the feldspars. Plain polarized light, X 32.
crystallized at any time between the Late Jurassic, date of vertebrate fossils from limestone fragments (Edwards, 1955, p. 157), and middle Eocene, approximate date assigned to the Red Conglomerate as based on vertebrate fossils. The Laramide orogeny (Rocky Mountain orogeny) overlapped both the Mesozoic and Cenozoic time boundaries; therefore, the granite might be placed just as correctly in the Mesozoic.

**Red Conglomerate**

The Red Conglomerate is confined to the hanging-wall portion of the Veta Madre in the area encompassed by this report (pl. 1).

Edwards (1955) made a study of the Tertiary Red Conglomerate in central Mexico, and his paper gives a detailed description of this sedimentary unit.

Edwards (1955, pl. 45) shows the contact between the Red Conglomerate and the granite as a fault. This is not the case, for a depositional contact can be seen 450 meters S. 60 W. of the Nueva Luz shaft.

Edwards (1955, p. 166) maintains "...the green color of the conglomerate that occurs in the mines along the Veta Madre may be explained as resulting from localized reducing conditions that were produced by hydrothermal alteration accompanying the mineralization." Various places where the Red Conglomerate is exposed in the deepest canyons and in the mine workings it has a green color. These sites are places where the erosion is exceeding the oxidation rate; hence the green color
of the conglomerate is an environmental feature and cannot be attributed to hydrothermal alteration.
STRUCTURE

General

Wisser (1960, p. 78) writes the following about Guanajuato:
".... the district lies on the northeast flank of a major anticline which plunges southeastward." The east limb of the anticline has three large faults that strike parallel to the anticlinal axis. One of these normal faults is the Veta Madre. The major anticline that Wisser describes could be an anticlinorium, a large first-order fold with smaller superimposed folds on the limbs of the major structure. Wisser (1960, p. 79) outlines the tectonic sequence as vertical uplift forming the Guanajuato anticline along with longitudinal tension fissures; intrusion of a batholith followed by differential movement along the blocks formed during the original uplift; and finally mineralization of the Veta Madre fault. Consequently, according to Wisser, the Veta Madre faulting is genetically linked to the original vertical upfolding of the region, and later shearing along the old tension fractures caused the rotational faulting along the Veta Madre.

Folds

The existence of a small anticline, plunging slightly to the
southeast, was not recognized until compilation of field data for plate 1. The axis of the anticline circumscribes a half reverse sigmoid flexure. Two explanations for this configuration are cross folding (fig. 8) or differential gravity gliding off of the limb of an anticlinorium. If a large anticline cuts through Guanajuato, as suggested by Wisser, then differential gravity gliding off of the limb of the anticline might create numerous small superimposed folds characterized by undulating axes. Cross folding could have deflected the axis of the small mapped anticline, and the inflections of the strike of the micritic limestone in various places indicate this possibility of cross folding. Detailed structural mapping will be required outside of the area mapped in plate 1 to determine the true structural relationships. However, if this area has undergone cross folding, it should be determined whether the folding was simultaneous or subsequent cross folding. Hills (1963, p. 276) believes active faulting in the basement could cause folds to develop, and while folds are developing secondary stresses in the sedimentary sequence might cause cross folding. Hills further suggests this action could produce local domes or basins. The writer believes it is probable an anticline trending northeast, not shown on plate 1, is responsible for the cross folding.

The type of folding could not be discerned in the field, but, according to Hills (1963, p. 234), if competent beds are interbedded with incompetent ones, "the competent bands exhibit parallel folding, but the
Figure 8.--Deflection of anticlinal axes caused by cross-folding resulting in a reverse sigmoid flexure pattern. Anticlines A and C have equal wavelength. The amount of amplitude is shown.

Modified from E.S. O'Driscoll, in Carey, 1962, P.157, Fig. 5.
overall pattern is that of similar folding with marked evidence of dif-
ferential flow in the incompetent ones, which adjust themselves to the
predetermined fold form." Thus, the shale and limestone sequence of
the Esperanza Formation is probably deformed into composite folds of
similar habit.

The horizontal projection of the line of intersection between
the Veta Madre and the axis of the anticline trends S. 75° W., plunging
41°. It is interesting to note (pl. 1) that if a line is drawn, with the
bearing given above, from where the axis of the anticline makes sur-
face contact with the Veta Madre the line trends directly toward the
main shaft of La Valenciana. Butler and Wilson (1942, p. 203) have
reported the ore deposits at Tombstone, Arizona, tend to be associated
with the crests of the folds because this is where the bending of the anti-
cline is sharpest, causing brecciation and fissuring to be most exten-
sive. The author does not suggest the anticline to be a fundamental ore
control at Guanajuato, but it does merit consideration as a possible ore
control at its intersection with the fault.

Faults

Wandke and Martinez (1928, p. 15) define the Veta Madre fault
as a rotational, fissured fault with 800 meters of displacement near La
Valenciana. They used the term fissure to denote filled faults. Perhaps
it would be more useful to utilize a recent definition of fissure (Mitcham,
1963, p. 1157): "A fissure is a fracture whose walls have been opened significantly by separation in a direction normal to the plane of the fracture."

Shattered zones adjacent to the fault have been very productive in Guanajuato. The difference in relative competency of the phyllite, limestone, and andesite units may account for the deflection of the Veta Madre. Knopf (1929) showed, in the Mother Lode system of California, that a fault is deflected toward the normal in more competent rocks and bent away from the normal when passing through incompetent rocks. Thus, the Veta Madre would be expected to steepen wherever it cuts through the competent limestone member (tend to approach right angles to the bedding) and hypabyssal andesite intrusives and to become more gentle as it passes through the less competent phyllite sequence (pl. 1, vertical sections).

Shattered zones could be expected to be located in the vicinity of limestone and andesite in the hanging wall. Normal faulting would cause much brecciation and fracturing of the Red Conglomerate in the hanging wall as it slides over the deflection in the footwall. The open spaces were later filled by ore minerals. The exact location of the shattered zones will depend on the movement of the hanging wall relative to the footwall.

Tension fractures (gash fractures) are apt to be best developed in the hanging wall; also, tension fractures caused by a possible small
strike-slip component would be expected to intersect the Veta Madre at angles of 45° to 60°.

Figure 9 is a photomicrograph, X 32, of a thin section cut from a green microcrystalline quartz vein that is 125 meters north of the Encarnacion shaft located on the north side of the highway from Guanajuato to Dolares Hidalgo. The vein must be a part of the Veta Madre or it is the Veta Madre at this location. This thin section is interesting as it illustrates a true fissure—the dilation is normal to the walls on both sides of the veinlet. A cursory inspection might cause one to believe the displaced veinlet was caused by a strike-slip component along the younger veinlet. The matrix is microcrystalline quartz, and the vein material is megacrystalline quartz. Both types of quartz are typical of vein quartz derived from pegmatites or hydrothermal solutions. This microstructure may be representative of the macrostructures along the Veta Madre. Geometrical projections made from the footwall to the hanging wall should consider the possibility that dilation has occurred along the Veta Madre.
Matrix of microcrystalline green quartz, Veta Madre. The veinlets are composed of megacrystalline quartz. Fracturing along the youngest veinlet is a true fissure—with dilation normal to the walls on both sides of the veinlet. A cursory inspection might cause one to believe the displaced older veinlet was caused by a strike-slip component along the younger veinlet. Plain polarized light, X 32.
MINERALOGY

The author did not conduct any studies of the mineralogy of the ores from Guanajuato. Wandke and Martinez (1928) include a section on the mineralogy, and a thorough report was written by Wilson, Milton, and Houston in 1950. They identified minerals, commented on paragenesis, temperature of vein formation, and included a description of the silver-gold veins. The most important silver minerals are argentite, polybasite, and pyrargyrite. They are usually associated with pyrite. Some of the other sulfides found in minor amounts include marcasite, sphalerite, chalcopyrite, and galena. The gangue minerals are quartz (clear and amethystine varieties), calcite, dolomite, and a variety of adularia called "Valencianite."
GEOLOGIC HISTORY

The writer's conclusions regarding the geologic history of this area are essentially the same as those presented by Edwards (1955). The entire geologic column of the region is not exposed in the area mapped for this report; hence, the brief outline given below represents only part of the geological history.

Mesozoic sediments were deposited adjacent to an orogenic belt in a marine environment of moderate depth(?). A thick sequence of Mesozoic clastic components accumulated with some interbedded micritic limestones. Tectonic action caused the sediments to be folded and uplifted. Hypabyssal andesitic intrusives invaded the Mesozoic sediments followed by granite intrusion that cut both sediments and andesite. The granite may represent a stock or fringe of a batholith.

During the original uplift of the Mesozoic sediments the Veta Madre fault probably had its origin as a tension fracture (marginal fault) on the flank of a large fold. Erosion exposed part of the granite pluton and the Mesozoic sediments. The Red Conglomerate was deposited nonconformably on the granite and unconformably on the Mesozoic sediments. According to Edwards (1955), the majority of fragments within the Red Conglomerate was derived from a northwest-trending mountain
range 10 or 15 kilometers from Guanajuato.

Large normal displacement along the old tension fracture created the Veta Madre fault. Sometime after early Oligocene the Veta Madre was metallized. This was followed by outpouring of effusive rocks contiguous to the area shown in plate 1.
CONCLUSION

Surface mapping of the footwall formations of the Veta Madre in the Guanajuato mining district suggests that both structural features and rock types found in the footwall adjacent to the vein may be influential in localizing ore bodies.

The intersection of the Veta Madre fault and the axis of the anticline may be a significant ore control. It is probable the axis will intersect the Veta Madre fault to the south of the area mapped on plate 1, and its position should be established by detailed subsurface geologic mapping.

Relative competency of the different rock units is a physical ore control that may have caused the shattered (ore-bearing) zones to be best developed in the hanging wall of the Veta Madre. Ore has been mined from all of the host rocks along the Veta Madre; therefore, chemical reactivity between the ore solutions and the host rocks was seemingly insignificant and cannot be considered an important ore control. However, the large stopes in the Rayas mine probably can be related to either a limestone or andesite unit lying in the footwall of the Veta Madre. Brecciated and shattered zones of known ore bodies may provide a geometrical connection that can be utilized to determine the
location of unknown shattered zones along the vein. Assuming that defection of the Veta Madre was caused by the difference of rock competency among the various host rocks, then a true geometrical correlation between the competent rocks and the stopes may provide a basis for correlation of competent rocks with unknown shattered areas.
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