THE MANTO TYPE LIMESTONE REPLACEMENT DEPOSITS OF NORTHERN MEXICO

Thesis by

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In Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

California Institute of Technology

Pasadena, California

1931

ABSTRACT

A study has been made of the principal manto type limestone replacement deposits of northern Mexico. Three of the districts, Los Lamentos and Santa Eulalia in Chihuahua, and Mapimi in Durango, are described in detail. The sedimentary rocks are correlated with the Texas Comanchean formations. The ore deposits are confined to certain beds of Upper Trinity and Lower Fredericksburg age. Data show that it is the physical and not the chemical properties of the limestone which make some beds more susceptible to replacement than others.

Folding and fissuring have been essential in localizing the ore deposits. Mantos have been found to occur, in general, in favorable beds at the crests of folds. The fissure zones are most pronounced in depth. The cross section of a deposit decreases upward from the apparent source altho the diminution is not constant. Mantos have yielded most of the ore in the upper deposits; chimneys become more important in depth. The analyses of sections of an ore body are uniform but the deposits show a gradual change in composition in a district. The ores are zoned vertically and laterally from the apparent source and are believed to have been deposited by magmatic waters. The principal deposits of a district were formed at one time. The metallic content of the bedded oxidized deposits is almost identical to that of the primary deposits from which they were derived. Dolomitization has occurred locally during oxidation.

THE MANTO TYPE LIMESTONE REPLACEMENT DEPOSITS OF NORTHERN MEXICO

Part I

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Part II

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GEOLOGY AND ORE DEPOSITS

OF THE

LOS LAMENTOS RANGE, CHIHUAHUA, MEXICO

by

F. L. RANSOME and J. WILFRED PATTERSON

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PART I

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by

J. W. PATTERSON

LOS LAMENTOS DISTRICT, CHIHUAHUA, MEXICO

Introduction

A study of the Manto Type Limestone Replacement Deposits of Northern Mexico will be presented in the following series of papers. Each district chosen for study shows mantos developed under definitely different conditions of igneous activity and structure. The final paper will summarize the criteria for recognition of manto deposits, with conclusions regarding the controlling factors of ore deposition. It is hoped these results will prove of value in the development of the known ore bodies and be of aid in the discovery of new deposits.

The Los Lamentos Range is composed of tilted Comanchean sediments that are little deformed. Any rocks, either intrusive or extrusive, which might have a genetic connection with the ore deposits are remote from the district. Altho the main ore body formerly was considered as an _ideal_ manto, the present investigation shows that only a minor part of the deposit is of this type.

ACKNOWLEDGEMENTS

The writer is deeply indebted to Dr. L. D. Ricketts, former President of the Ahumada Lead Company for making possible this study, for his suggestions and constructive criticisms.

Especial thanks are due to Dr. F. L. Ransome of the California Institute of Technology who has supervised this work and critically discussed its problems. Thanks are also due to the Board of Trustees, Dr. John P. Buwalda, and Mr. Rene Engel of the California Institute of Technology.

The staff of the Ahumada Lead Co., especially Mr. Charles Dobbell, former Superintendent, Mr. John Brooks, present Superintendent, and Mr. Byron Valle, have been most cordial in co-operating in every way. Mr. Ira B. Joralemon kindly discussed with me his views as to certain elements of the geologic structure.

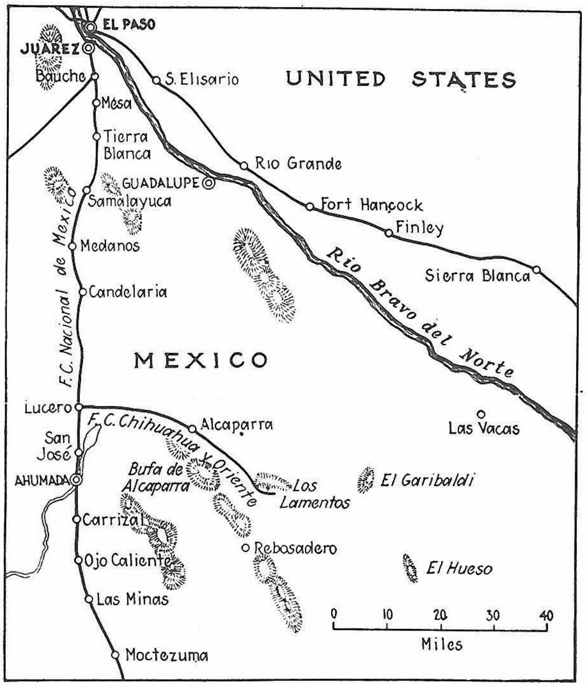
SITUATION

The Los Lamentos limestone replacement deposits occur in the Sierra de Los Lamentos, a short isolated desert range in the Bravos District, State of Chihuahua, Mexico. The range lies in latitude 30 degrees 30' north and longitude 105 degrees west, and approximately 90 miles south-southeast of El Paso, Texas. The deposits of this district are the latest of the noted "manto" type to attract world-wide attention. They are the most northerly of the producing areas studied in connection with this investigation.

From El Paso the district is reached by the National Railways of Mexico via Lucero and the Ferrocarril Chihuahua y Oriente to Felix U. Gomez, a total distance of 182 kilometers (112 miles) from El Paso. A mountainous barrier separates the district from the International Boundary, the Rio Grande, only 48 kilometers (30 miles) to the northeast.

Villa Felix U. Gomez, formerly Los Lamentos, the terminal of the Ferrocarril Chihuahua y Oriente, is situated at the southern base of the Sierra de Los Lamentos just south of the outcrops of the Erupcion-Ahumada Mine. The position of the Los Lamentos Range is shown on the index map (Figure No. 1).

The City of Chihuahua lies 220 kilometers (137 miles) south of Felix U. Gomez and the Santa Eulalia district is 15 miles east of that city. The mantos of Santa Eulalia are comparable to the type of deposits found in the Los Lamentos district.



Map of northern Chihuahua, Mexico, showing the location of the Los Lamentos Range in which is situated the property of the Ahumada Lead Co.

Fig. 1

FIELD WORK

The study of the Los Lamentos district ore deposits was undertaken in the summer of 1927 and continued during the summer of 1928. The geologic map and the chapters on stratigraphy and structure from an unpublished report on the "Geology of the Los Lamentos Range" were prepared by Dr. F. L. Ransome for the Ahumada Lead Company in 1926.

PREVIOUS WORK

Publications on the district, unfortunately, are confined to brief notices in mining and technical journals. The account by T. A. Rickard[1] which gives the most comprehensive published statement of the area and a short sketch by Geo. F. Eaton[2] are the only noteworthy articles available. Several confidential reports have been written concerning the deposits of which the report of Ransome is the most thorough, while the ore bodies have been admirably treated by Mr. Ira B. Joralemon, formerly consulting geologist for the Ahumada Lead Company. An earlier unpublished report was written by Mr. Basil Prescott in 1920.

One fundamental difference in Dr. Ransome's report is his interpretation of the structure and stratigraphy, which is not in accord with the views held by Prescott. Ransome summarizes Prescott's section as follows:

1. Rickard, T.A.--The Ahumada Lead Mine and the Ore Deposits of the Los Lamentos Range, in Mexico: E&M.J.-P., Vol. 118 pp. 365-373, 1924.

2. Eaton, E.F.--Vertebrate Fossils from the Mina Erupcion: Am. Jour. of Sci. 5th Series. Vol. VI, No. 33. Sept. 1923.

"TOP

(4) Upper Bufa beds.

Up to 1000 feet (305 meters) of solid clean limestone. Resembles the Los Lamentos limestone, but is more fossiliferous and not so distinctly bedded. Rough cliffy topography.

(3) Fetid fossil beds.

Two hundred feet (61 meters) or more of shaly limestone and interbedded black limestone. Numerous very minute black fossils.[1] Gives a fetid odor when struck. The middle part, near Los Lamentos, contains 2 or 3 beds like the Los Lamentos limestone. Over the Erupcion mine a single bed, not over 3 feet thick (0.9 meter), lies above the middle beds just mentioned and is readily recognizable by its characteristic red and dark gray mottling.

(2) Los Lamentos limestone.

Brownish limestone from 100 to 500 feet (30 to 152 meters) thick. Fossiliferous except in lower 30 to 40 feet, (9 to 12 meters), with large characteristic fossils[2] near top. The Los Lamentos limestone is thick-bedded at base and in upper fourth but in the middle shows no bedding. Thickness at west end of range about 75 feet, (23 meters); at east end about 300 feet (91 meters.)

(1) Blue limestone and shale.

1. Orbitolina texana. F. L. R.
2. Chiefly Caprina. F. L. R.

Consists of 3000 feet (914 meters) or more of shaly limestone interbedded with blue limestone in beds up to 12 feet (3.6 meters) thick. At top, 100 feet (30 meters) or more of pure blue limestone. Not over 300 feet (91 meters) exposed near Los Lamentos; rest, if present, under the valley filling. Few fossils.

BOTTOM

Aside from minor differences, there is an important discrepancy between the section as given by Prescott and that presented in the present paper. This is due to his view that the Sonora, Tlaxcala, Buena Suerte and Triste limestones of the present paper (see the accompanying geologic map), are a repetition by faulting of the beds enumerated in his stratigraphic column, whereas, as will be shown later, they are clearly younger and stratigraphically higher beds. The fault assumed by Prescott, in explanation of this supposed repetition, does not exist."

In probably the most important and enlightening paper relating to the limestone replacement deposits of northern Mexico, Prescott[3] does not note any Comanche beds above his Upper Bufa limestone.

3. Prescott, Basil. The underlying principles of the limestone replacement deposits of the Mexican province; E. & M. Jour. Press Vol. 122, pp. 122, pp. 247, '26

Mr. Eaton[4] in his article describes a section for which the late Mr. D. B. Smith is responsible, as follows:

> "The Los Lamentos is a Cretaceous limestone in beds dipping 14 degrees to the north. At the base is a blue non-fossiliferous limestone. Above this lies a bed of recrystallized limestone, which in turn is overlain by the orebodies, (largely lead and silver bearing minerals.) Above the orebodies are about 50 feet of dolomite with small fossils. Next in the series come 100 feet of limestone containing larger fossils; then 100 feet of "fetid beds" containing only minute fossils. From this ppint to the crest of the mountain about 1900 feet above the entrance of the workings, the limestone is described as merely fossiliferous."

4. i.d. pp. 231.

HISTORY

Apparently the first recognition of mineralization in the district was by a Mexican, Jose Maria de la Peña. Sr. Peña told Mr. D. B. Smith of the occurrence and Smith visiting the district 4 years later was favorably impressed by its economic possibilities. A 25 foot hole comprised the early workings on the present Erupcion claim. A fair showing of high grade lead carbonate ore was exposed. Preceding Mr. Smith's inspection, approximately 60 car loads of zinc ore had been shipped from a prospect in the Bufa limestone about 2 miles east of Villa Gomez.

A Mexican located the Erupcion claim in 1907 and the denouncement was later raffled and won by David Fenchler. Mr. Smith purchased the option from Fenchler in 1916 for $50,000.00. The same year he optioned the adjacent Labrador denouncement for $100,000. Exploration work was hindered by lack of water, and revolutionary periods. In October, 1918 Smith and E. F. Knotts, president of the company, were captured by Pancho Villa. They were released after payment of a $20,000 ransom. During the rest of Villa's activity, the mine was unmolested and received his protection.

Smith and his associates are entitled to the credit of really recognizing the possibility of the district. During 1917 about 7500 tons of ore, averaging 40% lead, were transported by wagon to Villa Ahumada, 45 miles west and shipped via the National Railway to Chihuahua City. In 1918, exploitation decreased, primarily thru lack of sufficient capital.

Mr. Henry C. Dudley, in 1919, became interested and brought it to the attention of his associates, Dr. L. D. Ricketts and the late J. C. Greenway. Options on adjacent property were obtained which with the controlling interest of the Erupcion were incorporated as the Ahumada Lead Co. After a detailed examination by geologists and engineers, including Basil Prescott, Ira B. Joralemon, and H. C. Dudley, the calculated ore reserves warranted the construction of a branch railroad to the National line. The railroad began operating August 16, 1922, and delivered the ore to C. Juarez, Chihuahua. The run from Lucero to Juarez was over the National R. R. of Mexico right of way.

On October 10, 1924, the company train was wrecked and robbed by bandits. This occurred a short distance south of Candelaria, a station approximately 65 kilometers (40 miles) south of C. Juarez. Apparently the bandits were recognized and, to avoid exposure, murdered the entire train crew together with the company's bookkeeper, and three employees of the National Lines, who were on the train.

Water for potable use in the town is transported from company wells 2 kilometers east of Lucero. The mine pumps supply an ample amount of water for other purposes.

REGIONAL TOPOGRAPHY

Many geologists have recognized that northern Mexico thru distinctly contrasting topographic, geologic, and economic characters, falls into a number of natural divisions. From four to seven divisions have been postulated by these workers. The physiography of Mexico in a broad manner, has been treated by Freudenberg, Blackwelder, Ransome, Hill, Thayer, Suess[5] and others. There is apparently more accord of opinion regarding northern Mexico provinces than expressed in the literature concerning the physiographic divisions of southern Mexico.

A brief summary of the physiographic units will give a clear setting for the stage of this study which lies within the Mesa Central and adjacent Sonoran province where the manto deposits occur.

(1) Gulf Coastal Plain Province.

The most easterly unit of northern Mexico is known as the "tierra caliente" or Gulf Coastal Plain Province. It lies adjacent to the Rio Grande and is a continuation of the Gulf Coastal Plain of Texas. South of the international boundary the province narrows to a very thin strip between Tampico, Tam. and Vera Cruz;

(5)
Freudenberg, W.--Geologie von Mexico-Verlag Gebrüder Borntraeger, Berlin, 1921.
Blackwelder, Eliot--United States of North America Handbuch der reg. Geologie, 8, 1912.
Ransome, F. L.--Problems of American Geology Yale University Press--1915.
Hill, R. T.--E.& M.J. 72, pp. 563; 84, pp. 631; 85, pp. 681; Tran. A.I.M.E. Vol. 32, pp. 163-178, 1902.
Thayer, Warren--The Physiography of Mexico. The Journal of Geology Vol. 24, 1916. Pages 61-94.
Suess--Face of the Earth.

and is composed of sedimentary rocks of Cretaceous and Tertiary age that have a broader distribution in Texas. The rocks, in general, have been subjected to very little deformation other than gentle folding.

Petroleum and the major coal deposits of Mexico occur in this province.

(2) Sierra Madre Oriental Province.

The eastern front of the physiographic unit known as the Sierra Madre Oriental is a very precipitous scarp that marks the western limit of the Gulf Coastal plain. The Sierra Madre Oriental mountain system is considered by many as part of the Mesa Central, viz, Mexican Cordilleran province; other investigators consider them a southerly extension of the Rocky Mountain system, hence, to be referred to as a distinct province. The eastern limit of the province is distinguished by a steep overthrust fault which in places is a double overthrust. The latter phenomena is a prominent feature near Cruz, Tam. The mountains form a drainage divide except in the few places where the streams have penetrated the Mesa Central Province. The eastern Sierra Madre is cumulative in elevation from north to south. It rises to 5,000 feet at the U. S. Border and attains an elevation of 10,000 feet or more south of the Tropic of Cancer.

Stratigraphically the Sierra Madre Oriental province is unlike the Rocky Mountain system in which intrusive rocks predominate, as it is composed chiefly of faulted Cretaceous sedimentaries in the northern part of Mexico. Farther south extrusive rocks become dominant. The metalliferous deposits are associated with the intrusives, scattered masses of granitic and monzonitic rocks, but their economic importance is dwarfed by those of the adjacent Plateau province.

(3) Mesa Central Province.

The Mesa Central or Mexican Cordilleran Province is the major physiographic unit of Mexico. It is a wedge shaped area, diminishing in width from the International border toward the south. The Plateau, as it is commonly called, is bounded on the east by the Sierra Madre Oriental and on the west by the Sierra Madre Occidental. These ranges do not present bold fronts toward the Plateau province, but usually extend outward with rather gentle slopes upon the Mesa. The Plateau and the bordering Sierra Madres converge and terminate against the transverse Volcanic province of southern Mexico. It merges indefinitely with the intermontane plateau region of the United States that lies between the Rocky Mountains and the Sierra Nevada. The surface of the Mesa Central is a broad expanse of undrained territory broken by steep, short ranges rising above the floor of the plateau. These ranges have, in general, a north-northwesterly trend. The broad basins occasionally have shallow or dry lakes. The elevation of the plateau increases from 4000 feet near the border to over 8000 feet near Mexico City. The abrupt ranges rising out of the Mesa attain an altitude of several thousand feet. Geologically the Mesa is divided in two sections. The eastern part of the wedged shaped plateau consists mainly of sedimentaries of Mesozoic age, principally Cretaceous limestone. The western part is characterized by early Tertiary volcanics and where erosion and deformation has occurred the underlying Cretaceous strata is exposed. Frequently mineral deposits are found in such exposures. A typical example is the block of Cretaceous limestone in which the Calera mine was developed in the district of Guerro.

Most of the larger vein type silver producers of Mexico are associated with the Tertiary volcanics of the Cordilleran province. The eastern part of the plateau embraces the manto type lead-silver deposits with one known notable exception. It is very probable that similar deposits lie undiscovered beneath the volcanic covering of the western part of the Mesa. The sedimentaries of the plateau are very often cut by intrusives, especially monzonitic rocks, and these generally have mineralization associated with them. However, it is noteworthy that several of the major manto deposits are not closely or obviously associated with igneous rocks.

The short isolated ranges that stud the surface of the Mesa Central are the result of vigorous Post Comanche deformation. Gentle to sharp folding, in which overturned folds and overthrust faults are common, is a feature of these short ranges.

The Sierra de Los Lamentos is an example of the type of range that rises abruptly above the desert floor.

The Cordilleran Province is the important lead-silver-zinc producer of Mexico.

(4) Sierra Madre Occidental Province.

The Mesa Central rises with rather gentle grades in the west and merges with the eastern slope of the Sierra Madre Occidental. The northern part of the western Sierra Madre is a more contrasting unit than the eastern Sierra Madre Oriental. The western slope of the Sierra Madre Occidental forms a very steep barrier between the Plateau country and the Sonoran Province. The mountains almost disappear as an orographic unit near the International boundary, while just south of the border the peaks immediately attain an altitude of over 9000 feet. This province merges indefinitely with the short ranges of southern Arizona and western New Mexico. Some investigators hold that the Colorado Plateau is an abutment for this Province.

The Sierra Madre Occidental is composed largely of Tertiary volcanics and intrusives, probably resting on Cretaceous limestone. It is one of the most rugged and least studied areas of North America. To the south the peaks attain greater altitude and finally disappear beneath the cover of the transverse Volcanic Province of Mexico. The Sierra Madre Occidental is a heavily mineralized but little developed area. Lack of transportation, hostile Indians and almost inaccessible areas account for the small development to date.

(5) The Sonoran Province.

The Sonoran Province is immediately adjacent to the west of the Sierra Madre Occidental. It is the Mexican continuation of the Nevada Great Basin Province and is commonly known as the

Nevada-Sonoran Province. The large copper districts of southwestern U. S. and Sonora occur within this province. The predominating rocks are Tertiary flows and intrusive masses, with an occasional block of Cretaceous limestone exposed as a result of block faulting. The limestone is usually interbedded with volcanic materials, especially ashes, and the exposed blocks are sometimes mineralized. Such an occurrence will be described in a later paper on the Oposura Manto. The Gulf of California is probably a submerged part of the Nevada-Sonoran Province.

(6) Lower California

Lower California is a continuation of the Coast Ranges of California.

LOCAL SETTING

The Los Lamentos is a relatively short range rising abruptly above the broad desert floor of the Mesa Central. Its general trend is N 65 degrees W. The trend is a slightly more westerly than characteristic of the neighboring ranges. The local setting is shown on the reconnaissance map, Plate No. 1.

Southwest, across a broad desert valley, lies the long, narrow Sierra del Fierro. This range is about 9 miles from the base of Los Lamentos Mountains. The limestones in the Sierra del Fierro have been greatly faulted and in places stand on end or even overturned. The limestone is, for the greater part, equivalent to the "Bufa" limestone of the Los Lamentos range. Near the southern end of the Fierros, Angela (blue) limestone is exposed; and a large rectangular area of brown shale and sandstone extends east from the base of the range. Most of the sandstone has been metamorphosed to quartzite. This appears to be equivalent to the Perdido quartzite which will be mentioned later.

The Perdido Range lies 12 miles north-northwest of the Los Lamentos Mountains. It has a due north-south trend. Stratigraphically the rocks are equivalent to the lower section exposed in the Los Lamentos range, including the Angela, the Los Lamentos, San Vicente, and Bufa limestones. The Bufa formation forms the crest of the Perdido Range. However, about a mile to the east, flanking the southern half of the Perdido Range, is a short range, the Sierra del Goribalbi, which is composed of limestones of the Washita division of the Comanche Series. Metamorphosed sandstone, the Perdido quartzite, outcrop in a number of low knolls a short distance west of the Perdido range.

Northeast of the Perdido range is a very imposing barrier, the Sierra del Borracho. The western front of this range is composed of quartzites, sandstones, and shale capped by a thick series of limestones.

Eighteen miles due east of the southern tip of the Los Lamentos range is the Sierra del Hueso. The section exposed in this long, narrow, north-south trending range, is a repetition of the lower limestone formations of the Los Lamentos Range.

Twenty-two miles to the west, across a broad desert plain, are the Alcaparra and El Gorrion ranges. The Sierra de la Alcaparra may be considered as three units. Sierra Helena is an imposing limestone peak forming the southern unit of the chain. The central member, the Sierra de la Alcaparra, is composed entirely of limestone and the bluff, or "Bufa" Alcaparra, appears as a majestic stocklike landmark. The range has been subjected to much deformation and a great thickness of Angela (Blue) limestone is found exposed near the southern end of the range. The third unit, Los Cerros de las Minas is separated from the Sierra de la Alcaparra by a narrow valley. The Mosqueteros Mine and the Mexicana prospect occur in this range. Andesitic flows bank against the northern slope and continue to the north across the F. C. Chihuahua y Oriente right of way.

The Sierra del Gorrion is 30 miles N 45 degrees W from the

Los Lamentos range and five miles due north of Los Cerros de las Minas. The southeast face of this range is composed of limestones that are flanked on the north and west by intrusives and andesitic rocks. The limestones have been greatly deformed and metamorphosed near the monzonite porphyry. Garnet is abundant in the metamorphosed zone.

The monzonite porphyry is the nearest exposed intrusive to the Los Lamentos district. The mineralization on the several prospects located in this range can probably be ascribed to the effect of the porphyritic intrusion.

STRATIGRAPHY AND STRUCTURE OF THE LOS LAMENTOS RANGE

by

F. L. RANSOME

STRATIGRAPHY AND STRUCTURE OF THE LOS LAMENTOS RANGE

BY

F. L. RANSOME*

GENERAL FORM OF THE LOS LAMENTOS RANGE

Broadly viewed, the Los Lamentos Range is a homocline of limestone, crescentic in plan, that trends north 65 degrees west and presents its steeper and concave front to the south-southwest. The average dip of the beds is approximately 20 degrees to the north-northeast. The total length of the mountain mass, so far as it projects above the valley fill, is about 6 miles (9.6 kilometers). Its greatest width is about 3 miles (4.8 kilometers). The highest peak, La Bufa, rises to an elevation of 2,005 meters, or 6,578 feet, above sea-level.

In addition to the generally simple, crescentic, homoclinal ridge which forms the main body of the range, there are, to the north, a few smaller elevations that are structurally a part of the Los Lamentos Range but which are superficially separated from the principal mass by areas of alluvium. The largest of these is Buena Suerte Mountain (also known by its older name of Triste Mountain). This mountain also is conspicuously and regularly homoclinal in structure, the component beds dipping from 10 degrees to 25 degrees to the north-northwest. The summit of Buena Suerte is 1776 meters above sea.

*Section from "Report On The Geology Of The Los Lamentos Range" By F. L. Ransome for the Ahumada Lead Co. 1926

Other, much smaller, hills rise from the alluvium north and east of Buena Suerte Mountain. They are composed of massive limestone, in which the bedding planes as a rule are too obscure to present clear indications of structure.

STRATIGRAPHY

General features.- The rocks of the Los Lamentos district, exclusive of the unconsolidated Quaternary wash, are exclusively limestones with a very minor proportion of calcareous shales. No igneous rocks are present. All of the beds belong to the Comanchean or Lower Cretaceous series. The limestones in general contain very little magnesia and are dolomitic only where they have been modified by magnesium-bearing solutions in connection with ore deposition. Practically all of the formations are fossiliferous but in many of the beds the fossils are scanty, fragmentary, or do not weather out or break out so that satisfactory collections can be made by ordinary methods. The beds range in thickness from those so thin that the rock is shaly to those so massive that no traces of bedding can be detected through thicknesses of 50 feet (15 meters) or more.

There is not much general color-distinction between the weathered limestones of the Los Lamentos Range. The prevailing tint is light brown but this varies locally from dark brown to light gray. Conspicuously light hued limestones, such as are seen at Bisbee, are wholly absent. On closer view, the weathered surfaces of the Angela ("blue") limestone are generally blue-gray and similarly colored beds may be seen in the San Vicente ("fetid") Sonora, Buena Suerte, and Triste formations.

A generalized columnar section of the limestones is shown in figure 2.

<u>Angela limestone</u>.- The Angela limestone, locally known as "the blue limestone," is exposed at the surface only along the southwest base of the Los Lamentos Range for a distance of about 4½ kilometers, between Fragua Canyon on the northwest and La Mexico mine on the southeast. In most places it forms a steep slope below the base of the overlying cliff-making Los Lamentos limestone but locally the slope on the upper beds of the Angela limestone merges with no topographic break into the generally more precipitous front presented by the Los Lamentos limestone. Towards the south and southwest, the Angela limestone is overlapped by the detrital Quaternary deposits that floor the valleys of the region. The lower part of the limestone is therefore nowhere exposed within the area studied.

Thoroughly typical exposures of the Angela limestone may be seen directly behind the company's guest house at Los Lamentos and in the lower part of the slope that rises to the northeast from the end of the Chihuahua y Oriente Railway, east of the town. The name used in this report is taken from the Angela mining claim of which the southwest corner is on this limestone. The change from the local usage of "blue limestone" was made to conform to the practice of the U. S. Geological Survey, followed generally by geologists in the United States, of giving to each geologic formation a geographic name, derived from a locality at or near which the formation is typically exposed.

The Angela limestone is characteristically of a dark blue-gray color and very compact in texture. The beds are of moderate thickness and range from about one inch (2.5 centimeters) to 9 feet (2.7 meters). Few beds in the Angela limestone, however, are over 6 feet (1.8 meters) thick and the average thickness is probably about 2 feet (0.6 meters). A rather characteristic feature where the beds are exposed in bluffs, as behind the company's guest house is a rough vertical fluting due to the more rapid solution of the exposed edges of the beds along cracks or joints perpendicular to the bedding. Prescott in one of his reports fefers to this feature as a "chiselled effect."

Chemically the Angela limestone is a slightly siliceous but otherwise very pure limestone. A composite sample, taken across the section of this formation exposed just east of Los Lamentos, was determined by Critchett and Ferguson, chemists and assayers of El Paso, to contain

	Per cent
SiO_2 - - - - - -	2.95
CaO - - - - - -	51.7
MgO - - - - - -	0.14

Although not entirely unfossiliferous, the Angela limestone contains so few fossils and those so poorly preserved, that no collection was made. The fossils seen appeared to be chiefly small indistinct corals.

Although the distinction between the Angela limestone and the Los Lamentos limestone is, in a general way, obvious enough, the exact plane of demarcation between the two formations is not everywhere apparent. As a rule the two limestones differ in the color of their surface exposures, the angela being blue-gray and the Los Lamentos brown or buff. The bedding of the Angela limestone is distinct, while in most of the Los Lamentos, planes of stratification are obscure or lacking. This is on the whole the most useful distinction underground, where the absence of bedding surfaces in the Los Lamentos contrasts with the smooth, regular planes observable in the Angela, There is a difference in texture, the Angela limestone being dense and breaking with a conchoidal or splintery fracture, the Los Lamentos being slightly more open textured. Locally the Los Lamentos limestone has been dolomitized and has a distinctly granular texture, whereas the Angela limestone has been only slightly affected, if at all, by this kind of alteration. Because of its more massive character, the Los Lamentos limestone, in sections across the bedding, commonly forms a cliff or precipitous scarp while the Angela limestone forms a smooth or stepped slope. As a rule, in surface mapping, the most useful criterion, and the one generally used in drawing the boundary between the Angela and Los Lamentos limestones, is the transition from the comparatively unfossiliferous Angela limestone to a bed, about 6 feet (1.8 meters) thick, that is crowded with corals and some shells. Some of the corals are 4 or 5

FIGURE 2. GENERALIZED COLUMNAR SECTION OF THE ROCKS OF THE LOS LAMENTOS RANGE.

	NAME	MAX. THICKNESS	DESCRIPTION	AGE
			Coarse, stony detritus; sand gravel and soil. 'Wash'	Quat.
	Triste l.s.	500	Thick-bedded, cliff-making, pale brown limestone.	WASHITA, COMANCHEAN
	Buena Suerte l.s.	600	Thin-bedded l.s. Fossil sea urchins near base. Forms generally smooth slope.	WASHITA, COMANCHEAN
	Tlaxcala l.s.	500	Massive, cliff-forming, pale brown limestone. Fossiliferous at top.	WASHITA, COMANCHEAN
	Sonora l.s.	500	Generally thin-bedded, gray limestone with some bluff-making members. Fossils scanty.	TRINITY, COMANCHEAN
	Bufa l.s.	1500	Massive buff limestone. The most prominent cliff-maker in the region. Fairly fossiliferous.	TRINITY, COMANCHEAN
	San Vicente (Fetid Beds)	500 800	Shaly gray limestone crowded with small fossils (Orbitolina texana).	TRINITY, COMANCHEAN
	Los Lamentos l.s.	650	Massive buff limestone. Abundant fossils in upper part. The principal ore-bearing formation.	TRINITY, COMANCHEAN
Base not exposed	Angela l.s. (Blue Limestone)	700	Generally rather thin-bedded, blue-gray limestone. Fossils scarce.	TRINITY, COMANCHEAN

inches (10 or 13 centimeters) long. This is taken as the basal bed of the Los Lamentos limestone and generally marks the base of the Los Lamentos cliff.

Only the upper part of the Angela limestone is exposed in the Los Lamentos Range, the lower beds being concealed by Quaternary alluvium. The thickness of the formation is therefore unknown. A well drilled by the company in Los Lamentos, about 40 meters northeast of the railway station, penetrated 233 feet (70 meters) of alluvial wash and then went into what is apparently the Angela limestone and continued to a depth of 1400 feet (427 meters). Here an ample supply of water was tapped which rose to about 600 feet (183meters) from the surface. Examination of the churndrill cuttings from this well show that the material passed through is predominantly compact blue-gray limestone although from "392 to 463 feet" the cuttings are from a somewhat lighter-colored gray limestone. From "628 to 653 feet" and from "741 to 784 feet", the chips are not so clean and may have come from more shaly beds. None of the material from the well affords any definite indication that the bottom of the Angela limestone has been reached.

The very dense texture of the Angela limestone is not favorable to mineralization and no important ore bodies have been found in this rock.

Los Lamentos limestone.- The Los Lamentos limestone conformably overlies the Angela limestone and, like that formation, is exposed along the steep southwest front of the Los Lamentos

Range. As the geologic map shows, however, it extends considerably farther east than the Angela limestone and makes up the southern part of Juarez Ridge, in the southeastern corner of the area mapped.

In its topographic expression the Los Lamentos limestone appears as a rough precipitous slope which in many places may fairly be termed a cliff

The prevalent color of weathered surfaces is brownish gray or buff. Where unaffected by ore-bearing solutions, the limestone effervesces freely with dilute acid, is compact in texture, and in places is spotted with white calcite that has filled the cavities of fossil shells.

The Los Lamentos limestone is generally thick-bedded with rather indistinct partings between the beds. The upper middle portion is particularly massive. Towards the top, rather indistinct bedding planes, from 3 to 10 feet (0.9 to 3 meters) apart can be recognized in weathered exposures. These planes, however, are not nearly so distinct and persistent as those in the Angela limestone. A feature that appears as a bedding plane in one part of a cliff may be found disappearing in massive limestone a few feet away. Such bedding planes would probably not be recognizable in fresh limestone underground.

Although the Los Lamentos is fossiliferous throughout, the fossils in the lower part are chiefly corals which do not separate from their matrix in collectible form, although they are conspicuous on weathered surfaces of the rock. The most abundant and conspicuous fossil in the upper part of the formation is a large irregularly coiled lamellibranch shell (Caprina sp. ex. aff. crassifibra Roemer). On many weathered surfaces these shells appear as circular, elliptical or oval sections, many of these showing portions of a curved black shell with a filling of white calcite. The visible fossils are generally the left valve of the shell, the right being comparatively small and flat. The topmost bed of the Los Lamentos is thickly crowded with the remains of Caprina and as the overlying shaly San Vicente limestone has in most places been eroded away from the top of this bed for a width of some feet from its outcropping edge, the bared surface of the bed appears closely studded with the shells of Caprina.

Normally the Los Lamontos is a nearly pure limestone. Partial chemical analyses by Critchett and Ferguson show the following:

	Per cent		
	SiO_2	CaO	MgO
Upper Los Lamentos limestone	0.68	53.6	0.13
Lower " " "	0.40	53.0	0.20

In the general vicinity of the ore deposits, however, the limestone has been extensively dolomitized and shows a change of texture to a distinctly granular rock--the so-called recrystallized lime. The change in chemical composition is generally accompanied by a change in color from gray to red. The red appears first as small indistinct streaks of iron oxide in the predominantly gray rock but some of the more completely dolomitized parts of the formation are dark reddish gray with films of red iron oxide along joint surfaces.

Underground, the Los Lamentos limestone rarely shows any bedding planes. Where dolomitization has not taken place, the fossiliferous character of the formation is easily apparent.

The observed thickness of the Los Lamentos limestone ranges from about 200 feet (61 meters) north of Los Lamentos to about 650 feet (198 meters) north of La Mexico mine. This is a rather remarkable change to take place within a distance of less than 2 miles (3.3 kilometers) but it appears to be due to an original difference in deposition and not to any faulting or folding.

San Vicente limestone.- The San Vicente limestone, which has been locally known as "the fetid limestone" or "the fetid beds," derives the name used in the present report from San Vicente Wash, near the head of which the beds of this formation are well exposed. The local name is expressive of the fact that most of the San Vicente limestone gives a petroleum-like odor when struck with a hammer, but this property is not exclusive with the beds of this particular formation*

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* There is a current belief that the odor given off by this limestone, when the rock is drilled underground, makes the miners ill, and the reported absence of this effect upon the men who sank the main shaft below the Marjorie tunnel of the Erupcion mine was cited to show that the shaft did not pass thru this limestone. Examination of the shaft, however, showed that the full thickness of the San Vicente limestone was penetrated.

The San Vicente limestone lies conformably upon the topmost highly fossiliferous bed of the Los Lamentos limestone and is exposed all along the southerly face of the Los Lamentos Range from San Vicente Wash to Fragua Canyon, a distance of about 3.5 miles (5.6 kilometers). The position of its outcrop is easily recognized topographically; for, on account of its prevailingly thin-bedded character, it forms a relatively smooth slope that intervenes between the bold bluff of the underlying Los Lamentos limestone and the still more imposing cliffs of the Bufa limestone which forms the crest of the range. Moreover, because of its less resistant character, the San Vicente has in most places been eroded back from the brink of the Los Lamentos bluff, leaving a dip-slope bench in places up to 500 feet (152 meters) wide, which affords a route of comparatively easy travel along the elsewhere extremely steep and rugged front of the range.

The San Vicente limestone is for the most part thin bedded, with almost a shaly lamination that becomes more noticeable on weathering. The prevailing color is dark gray.

The most characteristic feature of these thin beds is the extraordinary abundance of small, dark discoidal fossils, which in many places appear to make up at least a third of the rock. These fossils are little disks, up to about 20 millimeters in diameter. One side is a low cone with fine concentric striations-like contour lines around a pointed hill; the other side is shallowly concave--like a tiny batea. These little shells are the remains of one of the larger species of foraminifera--*Orbitolina texana* Roemer, and are particularly characteristic of the beds of the lowest or Trinity division of the Comanche period. A few imperfect shells of lamellibranchs, especially Diceras sp., were also found in the thin beds of the San Vicente limestone.

About half way between the top and bottom of the San Vicente limestone, throughout the western two thirds of its exposed length, is a more massive member that forms a persistent bluff in the generally rather smooth slope. This member, which is shown on the geological map and sections, is in places practically one bed from 25 to 50 feet (7.6 to 15.2 meters) thick. At its eastern end, however, the member splits into 3 or more thinner beds which, towards the east, lose their identity as a distinctive member of the formation.

This massive member is abundantly fossiliferous, the observed forms being chiefly corals.

About 30 feet (9.1 meters) stratigraphically above the massive coral-bearing member or about 60 feet (18.3 meters) below the base of the Bufa limestone is a bed of hard compact limestone, in most places from 2 to 3 feet (0.6 to 0.9 meters) thick, characterized by a peculiar irregular mottling in dark gray and dull red, with locally abundant branching cylindrical corals and a few small poorly preserved shells. This bed is readily traceable along the slope of the mountain and has been identified in the Marjorie tunnel. As Prescott has pointed out in his report, it forms a useful stratigraphic marker and it is locally known as the "marker bed."

Above the marker bed, lie more thin shaly limestones with abundant Orbitolina. The distinction between the San Vicente limestone and the overlying Bufa limestone is not everywhere sharp. The line as drawn on the map represents in general the change from the slope on the thin-bedded San Vicente to the cliff formed by the more massive Bufa. Orbitolina, although particularly abundant in the San Vicente limestone probably occurs also in a few thin-bedded layers that are interstratified with the thicker beds in the lower part of the Bufa limestone.

The San Vicente limestone, as might be expected from its appearance, is not so pure a limestone as the Los Lamentos. Composite samples were taken from the beds above and below the massive middle member, which was not itself sampled. Critchett and Ferguson's determinations on these two samples were as follows:

	Per cent		
	SiO_2	CaO	MgO
Upper San Vicente limestone	3.90	50.6	0.14
Lower " " "	4.20	49.9	0.12

Alumina was not determined but is probably higher in the San Vicente limestone than in the Los Lamentos limestone. The San Vicente, however, is only slightly magnesian, practically no more so than the Los Lamentos limestone.

The thickness of the San Vicente limestone generally varies from about 315 feet (95 to 152 meters) to 500 feet. The steeply upturned beds of this formation exposed at the head of San Vicente Wash have an apparent thickness of about 800 feet (244 meters). There is possibly some repetition of the beds in this locality due to faulting.

Bufa limestone.- The name Bufa limestone has been applied rather loosely in Mexico to any limestone that outcrops prominently as a cliff along the crest of a mountain or ridge. It probably originated as stratigraphic name at Los Lamentos in this way. The highest peak in the range, situated about 0.8 mile (1.3 kilometers) northeast of Los Lamentos is designated on some maps as La Bufa and as La Bufa is composed of the limestone in question, this affords an opportunity to retain a stratigraphic name that is locally in use and at the same time to conform to the approved practice in naming geologic formations.

The Bufa limestone, which conformably overlies the San Vicente limestone, is by far the most conspicuous and extensively exposed stratigraphic unit in the district. It occupies the entire crest of the Los Lamentos Range and is the prevailing rock on the northerly slope which coincides in a rough and general way with the bedding planes; that is, broadly considered, it is approximately a dip slope.

The Bufa is generally thick-bedded, fairly fossiliferous and weathers buff or brown. In the lower 75 feet (22.8 meters) the beds range from 10 to 30 feet (3 to 9 meters) thick. Above these the beds are thicker and it is the edges of these massive beds that appear in the imposing cliffs on the south side of El Labrador and La Bufa peaks. Still higher in the formation the beds are again thinner, as may be seen in the vicinity of the pass between Fragua Canyon and Sonora Wash.

The original top of the Bufa limestone is not, so far as known, exposed in the district. On the northeast versant of the range and on the north side of Eloisa Ridge the Bufa beds are terminated upward by a surface of erosion that passes under the Quaternary wash. Between El Labrador Peak and Buena Suerte Mountain, the Bufa limestone is overridden, along the Sonora thrust fault, by the younger Sonora limestone. The relations here are not entirely clear but the thrust surface appears to cut obliquely across the bedding of the Bufa. The Bufa also near El Labrador Peak appears to have a part of its upper beds missing and to be thinner than to the northeast of La Bufa Peak. It appears probable, therefore, that the Bufa was originally thicker than is indicated by the beds now exposed in the Los Lamentos Range.

Corals constitute a large proportion of the fossil remains in the Bufa limestone and in certain beds are very abundant. Neither they nor the associated molluscan shells, however, can be readily collected and no attempt was made to obtain a representative collection of the fossil fauna. Two species of Vola, however, were brought in, *Vola quinquecostata* (Sowerby) and *Vola irregularis* Böse, of which the former is generally found in the Washita group and the latter in the Fredericksburg group, of the Comanche. There were also collected a few specimens of a large Lunatia [*Lunatia pedernalis* Roemer (?)] which occurs in the Trinity and Fredericksburg group and has been found at Bisbee, Arizona, and at many places in Texas. A Lima, Lima mexicana Böse, known from the Washita group in other localities, was also collected from the Bufa limestone.

No chemical analysis was made of the Bufa limestone but its generally close resemblance to the Los Lamentos limestone indicates that it is a pure limestone with very little magnesia.

As the original top of the Bufa limestone is not known the full thickness of the formation can not be determined. It is estimated that the total thickness of the known beds is at least 1500 feet (457 meters).

Sonora limestone.- The Sonora limestone, which is believed to be the next formation stratigraphically above the Bufa, derives its name from Sonora Wash, on the northeast side of which it is typically exposed.

The principal area of Sonora limestone lies between El Labrador Peak and Buena Suerte Mountain. A smaller area occupies the north end of Azteca Ridge.

The Sonora limestone is generally thin-bedded, compact in texture, blue gray in color, and contains only scanty and poorly preserved fossils. It thus has some resemblance to the Angela or "blue" limestone and was believed by Prescott to be identical with that formation. There are, however, distinct lithological differences, and such fossils as have been found in the Sonora indicate that it belongs above the Bufa limestone rather than below the Los Lamentos limestone.

Although the Sonora limestone is generally thin-bedded and in places shaly, certain groups of beds are fairly resistent to erosion and form bluffs or cliffs. The topography of the formation is on the whole relatively smooth in comparison with that of the Bufa and Los Lamentos limestones.

A few fossils were collected from the Sonora limestone in the small elliptical area exposed by the road, near the south base of Buena Suerte Mountain, and supposedly near the top of the formation. Among these Dr. Stoyanow identified Terebratulina guadalupae Roemer (?) which he states is usually found in the Austin chalk (Upper Cretaceous) of Texas, although at Los Lamentos it appears to be in the Comanche. On the north side of Sonora Wash, near its head, and just above the contact of the Sonora limestone with the alluvium, a few unsatisfactory fossils were found which Dr. Stoyanow identified as Modiola sp. He remarks that nothing definite can be stated about the species represented in this lot except that some of the specimens resemble certain groups of Modiola (Vorsella) described by Meek from the Cretaceous of the Great Plains. The evidence, such as it is, supports the conclusion that the Sonora limestone is a younger formation than the Angela or "blue" limestone.

As the original base of the Sonora limestone is not definitely known, the total thickness of the formation is not determinable. It is estimated that the known beds must have a thickness of at least 500 feet (152 meters).

Tlaxcala limestone.- The Tlaxcala limestone, named from the Tlaxcala mining claim, on which it outcrops, is exposed chiefly at the south base of Buena Suerte Mountain. There are also two smaller exposed masses of limestone that are referred with some doubt to this formation. One of these occurs at the northwest end of the ridge that extends along the northeast side of Sonora Wash. The other caps the narrow castellated spur at the northern end of Azteca Ridge. These two smaller masses directly overlie the Sonora limestone. The larger mass on Buena Suerte Mountain presumably has the same relationship to the Sonora but the contact is concealed by alluvial deposits.

In color and general appearance the Tlaxcala limestone closely resembles the Los Lamentos and Bufa limestones. It also resembles the younger Triste limestone, presently to be described. The practical lithological identity of these four limestones and the difficulty of making satisfactory fossil collections from them leads to some uncertainty in the identification of the limestone in the many small areas that are wholly or partly surrounded by alluvium in the northern corner of the mapped area. For example the limestone of the little hill that terminates the spur northeast of Sonora Wash, is mapped as Tlaxcala limestone because it overlies the Sonora limestone. It is indistinguishable lithologically, however, from the neighboring Bufa limestone only about 700 feet (213 meters) away, on the southwest side of Sonora Wash. The Sonora fault, as will be shown later, is believed to separate these two bodies of similar limestone. Lithologically the limestone of the chain of island-like exposures east of Buena Suerte Mountain and including the one in which is the Triste shaft, might be Los Lamentos, Bufa, Tlaxcala or Triste limestone. They are mapped, however, as Triste because this is the simplest explanation in view of their position with reference to the general structure of the district and to the type exposure of the Triste on Buena Suerte Mountain.

The Tlaxcala limestone is thick-bedded, the beds being for the most part from 10 to 12 feet (3 to 3.7 meters) thick. Fossils, especially corals, are abundant, some cup corals being up to 10 inches (25.4 centimeters) long. Some beds contain many shells, especially a form that was supposed in the field to be Caprina. The fossils are not readily separable from the limestone and no collection was made.

The thickness of the Tlaxcala limestone has been extimated to be at least 500 feet (152 meters).

Buena Suerte limestone.- The Buena Suerte limestone, named from Buena Suerte Mountain, outcrops as a girdle around that imposing honoclinal mass on its east, south and west sides. It conformably overlies the Tlaxcala limestone and underlies the Triste limestone which caps the mountain. Like the San Vicente limestone, the Buena Suerte is for the most part thinly bedded and forms a relatively smooth slope between the bluff outcrop of the Tlaxcala limestone below and the imposing cliff of Triste limestone above. Superficially the relations of the three limestones in Buena Suerte are suggestive of a repetition of the Los Lamentos, San Vicente and Bufa limestones--the view that is held by Prescott. There are differences, however, between the San

Vicente and Buena Suerte limestones, especially in their fossil content, which show that these two formations can not be identical.

The beds of the Buena Suerte limestone are generally less than 4 feet (1.2 meters) thick and some of them are shaly. The prevailing color is dark gray. Some of the thicker beds have a characteristic blotchy appearance, due to the presence of irregular dark-gray spots and streaks in a lighter gray matrix. None of the beds show the rather peculiar flaky lamination of the San Vicente limestone.

The fossil Orbitolina texana, which is so extraordinarily abundant in the San Vicente has not been found in the Buena Suerte limestone which, on the other hand, carries in its lower beds a fauna which is entirely different from that of the San Vicente limestone and is indicative of younger age within the great Comancho period.

Collections made in the Buena Suerte limestone include 4 genera of sea urchins, a brachyopod, an oyster, and a coral. The list of identified forms, with comments on them, was supplied by Dr. Stoyanow and is as follows:

Hemiaster elegans (Shumard). The characteristic fossil of the typical Fort Worth horizon, Washita group, Comanche series. Localities are Fort Worth, Fort Washington, and many other places in Texas.

Cidaris texanus Clark. Washita group. Found also in Bexar County, Texas.

Pedinopsis symmetrica (Cragin). Washita group. Found also on Sierra Blanca Peaks and near Kent, El Paso County, Texas.

Pyrina parryi Hall. Fredericksburg and Washita groups. Occurs at Leon Springs near San Antonio, Pilot Knob (Travis County), Kent, Sierra Blanca Peaks, and many other localities in Texas.

Kingena wacoensis (Roemer). This brachyopod has a definite zone of occurrence and is of great value for stratigraphic correlation. In Texas its position is at the base of the Del Rio clays of the Washita group. It has been found in other localities in Texas, in northeastern Mexico and on Vancouver Island.

Alectryonia carinata (Lamarck). In Texas this species is confined to one of the most persistent and conspicuous horizons of the Denison beds, Washita group. It has a wide geographical distribution.

Placosimilia mexicana Aguilera. This coral is characteristic of the Washita group and is found in the Cerro de Muleros, Chihuahua, Mexico.

The thickness of the Buena Suerte limestone is estimated at about 600 feet (183 meters).

Triste limestone.- The Triste limestone is named from an older designation for Buena Suerte Mountain, which appears on earlier maps. The mountain is still commonly known as Triste Mountain.[1] The Triste mine, which is merely a prospect, is also in the Triste limestone.

The Triste is a thick-bedded, cliff-making limestone, which in general appearance and color closely resembles the Bufa limestone. It is fossiliferous and certain beds are crowded with corals.

This limestone forms the cap of Buena Suerte Mountain and

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[1] The older name, meaning *Sad* or *Pensive Mountain*, is in keeping with the mournful significance of *Los Lamentos*. When, however, a mining claim was laid out over the mountain, it was evidently felt that a more cheerful touch was needed, so it was called *Buena Suerte* or *Good Luck*.

makes up a number of small hills that project above the alluvium in the northern part of the mapped area. At the north end of Azteca Ridge, a mass of the Triste limestone has been faulted down along the Azteca fault so that it abuts against the Sonora limestone.

The upper surface of the Triste limestone is an erosion surface that is unconformably overlapped by the Quaternary alluvium. The total thickness of the Triste is consequently unknown. It probably is considerably more than the 500 feet (152 meters) estimated for the known part of the formation.

Summary of the chemical character of the limestones.- For convenience of reference, the chemical determinations made upon the limestones of the Los Lamentos Range are assembled below. The samples were collected by traversing the edges of the beds as exposed in the face of the range near Los Lamentos and breaking a few fragments from as nearly as possible every bed. The aim was to obtain a fair sample of the formation as a whole, rather than of any particular stratum.

Tests on limestones

by

Critchett and Ferguson

	Per cent		
	SiO_2	CaO	MgO
1. Upper San Vicente limestone	3.90	50.6	0.14
2. Lower San Vicente limestone	4.20	49.9	0.12
3. Upper Los Lamentos limestone	0.68	53.6	0.13
4. Lower Los Lamentos limestone	0.40	53.0	0.20
5. Angela limestone	2.95	51.7	0.14

The above determinations were made to ascertain whether the Los Lamentos limestone was generally dolomitic or differed chemically to any marked degree from the limestones above and below. The differences found, however, were too small to encourage further work along this line. The quantity of magnesia present in any of the unaltered limestones examined is very small and it is fairly safe to conclude that the Bufa and younger limestones are also practically non-magnesian. Where, as is locally the case, the Los Lamentos limestone is dolomitic, this result has been effected by the action of magnesium-bearing solutions subsequently to the original deposition and cementation of the limestone.

Alluvium.- In the Los Lamentos region, as elsewhere in the arid southwest, the mountains rise abruptly above unconsolidated or partly consolidated detrital deposits that slope gently away from their flanks and merge imperceptibly into the broad desert plains. Near the mountains this material is more or less coarse and angular and is not distinguishable sharply from the stony debris that rests upon the mountain slopes--a fact that is indicated on the map by the use of a dotted line to separate the alluvial deposits from the older rocks. The material of these deposits has been washed from the adjacent mountain ranges, and, as a rule, the identity of the material from any particular range is recognizable for many miles from its base. Farther out, however, towards the middle or center of the valley, the material becomes finer, the particles more rounded, and the source less evident.

No particular study was made of the alluvial deposits that surround the Los Lamentos Range. They are not deeply dissected and consequently are not well exposed. Thin where they lap up on the mountain slopes, they doubtless are many hundreds of feet thick a few miles out in the valley. Where penetrated by the company's well in Los Lamentos they appear, from the records, to be about 230 feet (70.1 meters) thick. As water was not reached until the well was about 1400 feet (426.7 meters) deep, the alluvial deposits have no direct bearing on the water supply at Los Lamentos, although they would have to be considered in any search for underground water far out in the valley plains.

QUATERNARY FOSSILS

When the Marjorie tunnel broke into some caves at a point about 1130 feet (344 meters) from the portal or 50 feet (15.2 meters) beyond the first turn and 750 feet (228.6 meters) vertically below the surface, a number of bones were found which have been described by G. F. Eaton.[1] They include vertebrae of a wolf, of which the species was not definitely identified, leg bones of a young Pleistocene horse, and parts of the skeleton of a young deer. These animals apparently fell or wandered into these caves, or were perhaps washed in, at a time when some opening existed to the surface. No trace of such an opening was

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1 Vertebrate fossils from the Mina Erupcion: Amer. Journ. of Science, 5 ser., vol. 6, pp. 229-238, 1923.

found during the development of the mine, and it apparently had been filled by natural processes long before mining began, possibly at the time when the outcrop of the ore became sealed over with calcium carbonate.

STRUCTURE

Broadly considered, the Los Lamentos Range is a homocline of Comanche limestones with a general dip of from 20 to 25 degrees to the north northeast. That is, it is a tilted block in which the beds in general dip in one direction at nearly the same angle.

Such a homocline may conceivably represent either one limb of an anticline of which the crest has been eroded away, or it may be a tilted fault-block. On the supposition of anticlinal structure, nothing recognizable as the southern limb is known. South of Los Lamentos stretches a broad valley, some 7 or 8 miles (11 to 13 kilometers) wide, beyond which is the Fierro Range. This range has not been examined close at hand, but it does not appear to correspond to the southern limb of such an anticline as would account for the structure of the Los Lamentos Range.

About 1.5 mile (2.4 kilometers) west of Los Lamentos and south of the mapped area, a few low hills rise above the alluvium. These are composed of fossiliferous limestone that apparently is not the Angela limestone, but which can not be certainly identified with any of the other limestones of the main range. The fossils appear to be fragments of Caprina but no collection was made. The beds dip from 20 to 30 degrees to south 75 degrees west and do not therefore correspond in attitude to the beds of the main range. Their occurrence suggests the existence of an important fault under the alluvium, between these hills and the Los Lamentos Range.

On the whole, the evidence, although by no means satisfactory, points to the suggestion that the Los Lamentos Range is a tilted fault block, limited on the south or southwest by a great fault or fault zone that is now buried under the alluvial deposits of the valley.

Closer inspection of this supposed fault block brings out certain departures from an ideal, simple homocline.

Mapping of the formations along the south front of the range shows the existence of a low, transverse, anticlinal arch or buckle, with its crest northeast of Los Lamentos, approximately at the Erupcion mine, and trending about north. In consequence of this flexure the various belts of limestone, from the Angela to the Bufa, outcrop at successively lower elevations to the west and disappear under the alluvium at Fragua Canyon.

A more striking departure from simplicity than that just described is presented by the structure in the southeastern part of the area, in the vicinity of La Mexico mine and San Vicente Wash. From Fragua Canyon easterly past Los Lamentos to the La Mexico mine, the various limestones from the Angela to the Bufa, outcrop as regular continuous belts in which the beds dip regularly to the north at from 20 to 25 degrees. North of La Mexico mine, however, this regularity ceases and the Angela limestone disappears. At La Mexico mine the Los Lamentos limestone strikes north and stands vertically. At the head of San Vicente Wash the beds of the San Vicente limestone also strike about north and dip west from 65 to 75 degrees. East of the mine, in Juarez Ridge, beds supposed to be part of the Bufa limestone, also strike north and dip west, generally at about 65 degrees. In San Vicente Gulch, therefore, the Los Lamontos, San Vicente and Bufa limestones are not only steeply upturned but are actually overturned, so that the older formations now overlie the younger. At the head of the gulch the thin San Vicente beds are well exposed and show the actual change from a gentle northerly dip, such as they have along the main front of the range to a steep westerly dip, with a correspondingly abrupt change in strike. Along the line on the surface where the dip and strike change so sharply there is considerable crushing and disturbance of the beds. From certain viewpoints, the beds appear to have been sharply bent through an angle of more than 90 degrees. The overlying massive Bufa limestone, however, does not show a corresponding bend, and the only reasonable explanation of all the structural features in the vicinity appears to be the hypothesis that the abrupt change in dip and strike marks the position of a low-angle thrust fault--the Juarez fault (See Plate I). At the head of San Vicente Gulch and on the west slope of Juarez Ridge the outcrop of the thrust plane is fairly distinct. North of La Mexico mine, however, it is obscure, as indicated by its broken trace on the map, and in the massive Bufa limestone on the east slope of Juarez Ridge all attempts to trace it failed. In certain light conditions, such as sometimes occur in the late afternoon, the course of the Juarez fault over the slopes can be recognized from a distance, as from the road which leads from Los Lamentos around the end of Juarez Ridge to the old Los Lamentos mine. The best position for such an observation is a point on the road approximately south of La Mexico mine, a short distance outside of the mapped area.

On the east side of Juarez Ridge and in the vicinity of the old Los Lamentos mine, the massive character of the Bufa limestone makes it practically impossible to work out details of structure without the expenditure of more time than could be spared for this area. It is fairly certain, however, that the structure in general is that of a syncline overturned towards the east (See Plate I, section G G'). This structure also, when once suspected, can readily be recognized from a distance when the sun is in the right position. It is not so plain to one who is actually traversing this steep and rugged slope.

The faulting and folding of this eastern part of the Los Lamentos Range, as just outlined, are consistent with what is believed to be the mechanics of the process of deformation. Earth stresses of unknown origin appear to have exerted a strong thrust along approximately east-west lines. This thrust was relieved first by the folding of the limestone, the fold or folds being overturned towards the east. Later, a thrust-plane developed and the whole block of limestones that are characterized by the low northerly dips was shoved for an unknown distance over the block in which the limestones are folded, overturned, and show in general steep westerly dips. Still later, the thrust plane itself, the Juarez fault, was displaced by some steep normal faults, of which the San Vicente fault is the most conspicuous example. In the San Vicente limestone this fault is a bedding-plane slip.

It is quite likely that the gentle buckling of the limestones near Los Lamentos, already described, is a minor effect of the same stresses that produced the Juarez fault. The Sonora fault, presently to be described, may also be another manifestation of the same forces.

The Sonora fault, on the north side of the main Los Lamentos Range, about half way between the town of Los Lamentos and Buena Suerte Mountain, is in some respects a rather puzzling feature. As is indicated on the geologic map (Plate I) its trace on the surface appears to emerge from beneath the alluvium at the head of Sonora Wash and continue up a steep ravine to the crest of the spur that runs from El Labrador Peak northerly towards Buena Suerte Mountain. On the crest, it appears to turn northeasterly and continue down to the embayment of alluvial wash west of Azteca Ridge. A continuation of the same fault is believed to extend northeastward over Azteca Ridge. The fault throughout, it is to be observed, corresponds to the contact between the Sonora and Bufa limestones.

When the present investigation was begun, that part of the Sonora fault that runs from Sonora Wash to the crest of the ridge was recognized and, in fact, the existence of a fault along this ravine is apparent from the road that crosses Sonora Wash from Fragua Canyon. The exact position of the fault, however, was in doubt, and still greater uncertainty attached to the character of its throw and its continuation beyond the crest of the ridge. It was supposed to have a steep dip and to be identical with a feature known as the Sonora fault on the lower levels of the Ahumada mine. All attempts to trace the fault east of the crest of the ridge in a generally southeasterly direction had failed. The supposition had been advanced that the Sonora fault on the surface met a north-northeast fault, known as the San Luis fault, on the crest of the ridge, that both faults ended practically at the point of meeting and that the triangular block between them, occupied mainly by the Sonora limestone, had dropped 90 feet (27.4 meters) or so, like a wedge-shaped slice cut from a circular cake, the Sonora limestone being thus inlaid into the Bufa limestone at the point of the wedge.

In the course of the work, doubt as to this then current explanation began to accumulate. The possiblity of the meeting of two faults without either extending beyond the junction was admitted, but that neither strong fault should be traceable beyond the inter-section was regarded as improbable. Failure to find in the mine any structure that could satisfactorily be identified with the Sonora fault increased the doubt. Careful examination of the surface along the supposed courses of the Sonora and San Luis faults failed to bring out any satisfactory evidence of their existence as steep normal faults. Where the San Luis fault was supposed to cut certain beds of limestone these showed no displacement.

The Sonora limestone along its contact with the Bufa is generally exposed in a line of bluffs or cliffs with fallen blocks and talus along their bases. This feature alone suggests a sapping action along the base of the cliffs and a plane of structural weakness, such as a thrust fault would cause. Such rock exposures as are available along the east side of the Sonora wedge show much fracturing and disturbance such as might be expected in the vicinity of an important thrust fault. On the south side of the wedge the contact itself is concealed by talus but here also is more or less evidence of disturbance. The Sonora limestone itself, near the point of the wedge, is strongly shattered and shows much veining with calcite. This is a condition to be expected in the lower part of an overthrust block.

On the whole, although the structure is not absolutely demonstrable, I believe that the evidence points definitely to the conclusion that the Sonora limestone has been thrust from the north or north-northwest over the Bufa limestone. This relation is indicated in section A A', Plate I. The representation, however, is rather diagrammatic. The dip of the thrust plane can be only roughly estimated, and its relation to the bedding planes of the Bufa and Sonora limestones is conjectural.

The important practical consideration is that the Sonora fault, by this interpretation, is a low-angel thrust which lies well above the present mine workings and is not likely to have any structural effect on the known ore mantas. If a shaft is ever sunk near the south base of the Buena Suerte Mountain it will probably go through the Sonora thrust fault before reaching the Los Lamentos limestone and the known ore zones.

Towards the west, the Sonora fault would probably outcrop along Sonora Wash were it not covered by alluvial deposits. To the north its course over Azteca Ridge is very obscure, and its position on the map is there more or less conjectural.

Although the district as a whole is not greatly faulted, there are a few steep normal faults of some importance. One of these, named the Dos Amigos fault, crosses the main Los Lamentos ridge about a mile northwest of the town. This fault effects an apparent throw of about 150 feet (45.7 meters), the east wall having gone down. This displacement is plainly visible from the roads that lead westward from Los Lamentos. The dip of the fault is not known and the amount of throw mentioned is consequently only a rough estimate.

About one fourth mile east of the Dos Amigos fault is a similar fault, the Congreso, which splits into two branches to the south. The throw on this fault is in the same direction and apparently of about the same magnitude as on the Dos Amigos fault.

The Azteca fault, exposed at the northern end of Azteca Ridge is a strong dislocation that has dropped the Triste limestone on the northeast against the Sonora limestone on the southwest. Its throw must at least equal the combined thicknesses of the Tlaxcala and Buena Suerte limestones, or over 1100 feet (335 meters).

The Chihuahua fault, so far as exposed, is wholly within the principal area of the Sonora limestone. The east side has presumably gone down relatively to the west side but the amount of throw is not known.

The Buena Suerte fault, on Buena Suerte Mountain, apparently has a throw of from 150 to 200 feet (45.7 to 60.9 meters), the east side having gone down relatively to the west side.

The San Vicente fault, at the head of San Vicente Gulch, follows the bedding of the San Vicente limestone under the Juarez fault but cuts across the beds above that thrust plane. It apparently has a throw of over 200 feet, the west being the down-dropped side.

In addition to the faults of structural importance, the limestones are traversed by a number of fissures along which there appears to have been little or no displacement. Some of these fissures are single, but many of them are grouped as two or more closely spaced and nearly parallel fractures, constituting a sheeted zone.

Such fissures are rather abundant along the face of the Los Lamentos Range in the vicinity of the Erupcion mine, and some of the more conspicuous ones are indicated on the geological map. Some of them displace the limestone beds for distances up to about 10 feet (3 meters).

Although not structurally important, some of these fractures and fracture zones, as will be seen later, have been influential in directing or controlling the replacement of certain limestone beds by ore. At the surface, they themselves, like the larger faults, are not strongly mineralized. They may show considerable calcite, as the cement of shattered limestone or as vein material, and may be slightly stained with iron oxide. This zone of fracturing was probably a determining factor in the erosional development of this cliff and is known in the Erupcion mine as the "sideline fracture."

PART III

THE ORE DEPOSITS

by

J. W. PATTERSON

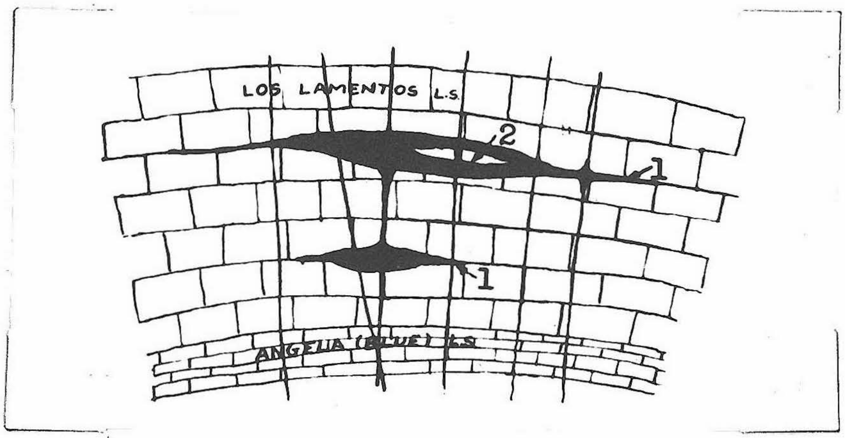
OREBODIES

Introduction.-- The main ore channel of the Los Lamentos district is called the Erupcion-Ahumada Manto. The ore bodies from the bottom of the mine to the surface follow the general bedding of the Los Lamentos limestone along or near the crest of a fractured, broad anticlinal fold. The general trend of the ore bodies is N 15 degrees W with a pitch to the north of 15-18 degrees.

To avoid ambiguity a definition of terms hereafter used are listed.

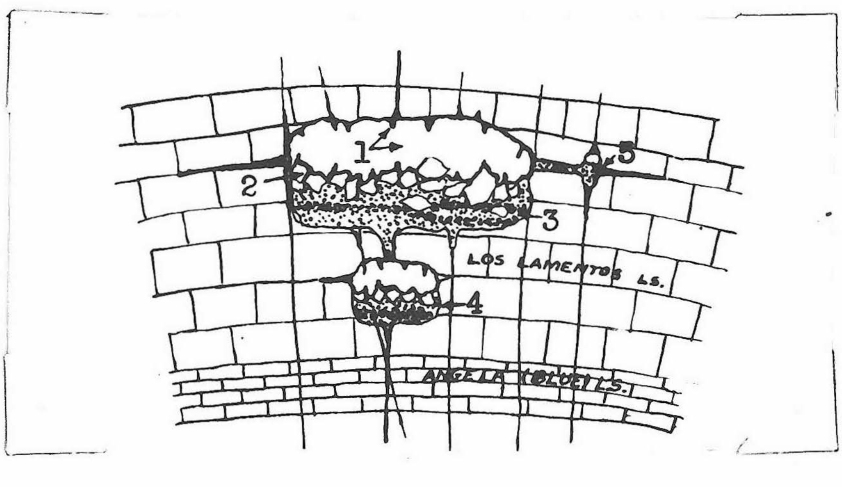
Manto is a Spanish term for horizontal veins or orebodies that follow the bedding of the enclosing rocks. A manto may then vary to follow any attitude the strata may assume. In Mexico, the use of the term has been generally restricted to an important group of limestone replacement deposits within the Mexican Cordilleran province. They are characterized by long, narrow ore bodies and differ from the run, flat, or blanket deposit in the rather constant ratio of length to width. The mantos of the Los Lamentos district have been complicated by another set of ore bodies that extend downward from the manto.

Sub-manto ore.-- locally called deep-ore, refers to the roots, or inverted mushroom shaped bodies beneath and connected to a manto. (See Figure No. 3). These bodies have yielded the bulk of the district production.



1. Sulphide manto, hilos and sub-manto ore.
2. Unreplaced lense of limestone.

FIGURE NO. 3A



1. Ore-bearing cave, calcite sealed.
2. Broken limestone blocks.
3. Bedded oxidized manto ore.
4. Bedded oxidized sub-manto ore.
5. Sulphide and semi-oxidized hilos.

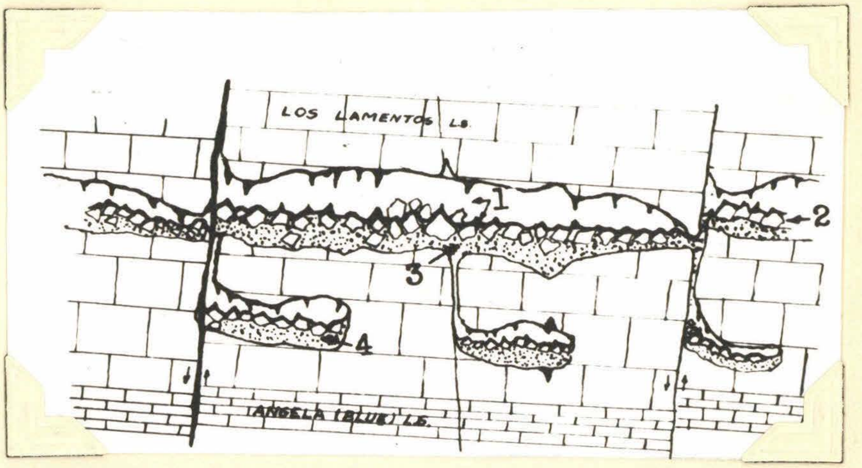
FIGURE NO. 3B

(FIGURES NO. 3A & B) IDEALIZED TRANSVERSE SECTION OF A MANTO AND SUB-MANTO ORE BODIES BEFORE AND AFTER OXIDATION.

<u>Chimney</u>-- An ore body roughly elliptical in cross-section which traverses the bedding of the enclosing rocks.

<u>Hilo</u>.-- the Spanish word for thread; when applied to ore deposits refers to thin mineralized seams or veinlets. In manto deposits, hilos are true mantos which are too thin for commercial extraction. The use of the term has become in general restricted to the thin blankets or beds, flanking a thick manto section. The differentiation of an hilo and manto in primary ore bodies is arbitrary and depends largely on the grade of the ore. (See Figure No.<u>3A</u>). Thin hilos were less susceptible to oxidation than thick mantos. Removal of limestone beneath a manto by acid solutions generated during oxidation lowers the oxidized ore relative to the site of the primary ore body. This leaves the partially oxidized hilos stranded above a manto. (See Figure No. <u>3B</u>).

<u>Ore-bearing Cave</u>.--locally called <u>shrinkage cave</u>. An "ore-bearing cave" is the open space existing above oxidized manto and sub-manto ore. It is formed by the lowering of the oxidized ore during oxidation thru removal of limestone beneath the manto section by acid solutions, and expedited by collapse which continued until the roof became a stable arch. The site of the primary ore is marked by the hilos which extend outward from the walls of an ore-bearing cave. Ore-



1. Ore bearing cave, calcite lined.
2. Broken limestone blocks.
3. Bedded oxidized 'manto' ore.
4. Bedded oxidized 'sub-manto' ore.

FIGURE NO. 4

IDEALIZED LONGITUDINAL SECTION OF A 'MANTO' AND 'SUB-MANTO' ORE BODIES.

caves have a greater breadth than height.

Barren-Cave.-- commonly called Dry-cave, is a product of oxidation. It marks a circulation channel during oxidation. The form varies from a cavernous fissure to large connected cave systems. The caves have greater height than width. They are usually barren, altho occasionally contain some secondary iron and zinc. A cavernous fissure or barren-cave system at some point is in contact with the ore body.

A generalized longitudinal section of a manto and the connected sub-manto ore is shown in figure No. 4. A generalized transverse section of hilo, manto and sub-manto ore and their relation before oxidation is seen in figure No. 3A. The differentiation of hilo and manto by oxidation is shown in figure No. 3B.

Structural features divide the main ore body into a number of sections that warrent description.

ERUPCION-AHUMADA ORE CHANNEL

The Erupcion-Ahumada ore body outcrops about 150 feet above the base of the Los Lamentos (Lower Fossil) limestone. The horizon has proved to be very favorable for silver-lead-zinc replacement deposits thruout northern Mexico. Originally the outcrop was concealed by a calcareous crust or caliche. The only suggestion of intense mineralization occurs in hard dense limonitic seams containing fine stringers or disseminated galena which heals a N W-S E shear zone.

of the manto followed a small, open NW fissure, lined with calcite and a few galena crystals. This fissure or water channel intersected a large cave of the main manto system about sixty feet from the surface. Subsequently ore found under the limestone boulders on the floor of the cave was in two places mined to the caliche covering at the surface.

Limestone from a fresh surface near the outcrop contains cavities with box-work and outlines pseudomorphic after pyrite.[1] The ore body from the point of penetration to the surface was a very irregular manto--[illegible] 10 to 50 meters in width. Near the top of the low ore-bearing caves, thin hilos of galena extend outward.

The N 20 degrees W, and the N 50 degrees E fissures cutting this section are occasionally heavily mineralized. The manto-ore was very low grade with a large amount of black iron oxide. Commercial ore was extracted by sorting or busconing. Lenses of good grade unmined ore probably remain in the sides of the caves; especially in the isolated sections outside the principal channels of oxidation. Surface leaching has apparently been an important factor governing the location of commercial bodies in this section.

Escondido Cave Section.--The succeeding seventy-five meters north was an ideal manto. The ore followed the bedding of the limestone with an almost equal pitch, altho the general

1. Blanchard, Rowland, & Boswell, P. F.-Econ. Geol. Vol. 20 1925

trend of the ore bodies is across the strike of the limestone. The limestone has a dip of 20 degrees and strikes N 25 degrees E.

Ore was stoped around and below the original cave and from the Escondido, Candalaria, and San Felipe caves, (See Plate No.3). The roof of the cave shows marked fracturing, by the NE and NS fissures with the NS group apparently governing the trend of this section. The ore was soft and increased in economic value proportional to the depth from the outcrop.

The manto reached a maximum width of 50 meters and a thickness of 25 meters. Lenses of sandy carbonate (lead carbonate or cerussite) occurred in the ferruginous ore. The NS fissures bordering this section were well mineralized. Very thin hilos occur high in the sides of the caves, altho the caves have steep, high side walls formed by collapse along N-S fissures. Some sub-manto ore is found associated with the N-S fissures which form the side walls of the ore-bearing cave. The carbonate manto-ore was underlain by a bed of very pure gypsum. Surface subsidence and caving have made the greater part of this section inaccessible.

<u>Gypsum Pillar Section</u>.-- The succeeding 125 meters north is called the Gypsum-Pillar section and yielded the first notable production of the Erupcion Mine. The ore was a hard, high grade, lead ore reaching a thickness of 10 meters, underlain by a lean gypsum layer. The gypsum occasionally enclosed irregular bodies of high grade ore. The Gypsum-Pillar area averages 40 meters in width, a decided increase over the sections previously described.

Several lenses of rich plumbojarosite have recently been extracted from this area. The hilos of plumbojarosite and galena reach a maximum thickness of one meter.

Sub-manto ore occurred associated with a strong N-S fracture zone in the western part of the section. A north-east fault zone marks the northern limit of the section. Disseminated sphalerite and galena occur in the limestone beneath the gypsum layer in the southern part. Enormous masses of gypsum and sulphur are found in the southern part of the Gypsum-Pillar section.

"A" Fissure Zone Section.-- The north-east fault zone limiting the Gypsum Pillar Section is the southern component of a wedge shaped fracture zone, the "A" Fissure Zone section. The N 60 degrees E fissure mentioned above dips 60 degrees northwest. A vertical N 75 degrees W fissure forms the northern limit. The bounding fissure zones apparently acted as lateral feeders within the favorable manto horizon, during the mineralization of the Berrenda ore body (See Plate No. 3).

The ore-bearing solutions responsible for the deposits south of the "A" Fissure section undoubtedly traversed the zone. However, the oxidized ore and cross-section are radically different from the normal. The leached ore within the section was very low grade, the manto thin and the cross-section small compared to the adjacent sections. Sub-manto ore is missing, tho, the enlarged fissures below the section contain secondary iron and zinc. The hilos are very immature.

Erupcion Section.-- North from the "A" Fissure Zone Section, the ore body for 300 meters has the typical manto form as to width and trend, and is very regular in character of ore. The width increases from an average of 60 meters at the southern end of the section to 100 meters near the Sideline Fault Zone marking the northern limit of the Erupcion section. The general trend of this unit is N 30 degrees W. The depth of the ore in the southern 175 meters increases from a thin, rich bed on the east to a maximum of 25 meters near the west limit with an average depth of 15 meters. The N 20 degrees W fractures in the west part of the section act as channels for the sub-manto ore.

The ore changed from a hard rich ore, underlain by gypsum on the east side, to a soft, fair grade limonitic ore in the western part of the manto. Secondary zinc occurs in the fissures above and below the stoped section. The ore-bearing caves are very low and sometimes missing.

Ore-bearing caves attain a greater size in the northern 125 meters of the Erupcion section. The ore of this second northern area also increases in depth and changes in character from the east to the west side of the ore body. Sub-manto ore is found associated with the N 10-15 degrees W fissures. Barren caves are associated with a number of prominent NE fissures which cut diagonally across the section. In places, the deep, barren-caves contain loose masses of high-grade ore and limestone blocks, which were probably washed or dropped into them from the manto above.

The sub-manto ore bodies associated with intersecting NW and

NE fissures resemble pipes or chimneys. These bodies extend to 150 feet below the manto ore. A longitudinal cross-section (See Plate No. 3) at first glance gives the impression of a decided increase in thickness of the manto. The increasing prominance of sub-manto ore bodies toward the north produce this illusion. The sub-manto bodies cross the bedding and at times penetrate the Angela limestone. They do not ordinarily connect with other sub-manto shoots. The ore is of the same character as the manto ore and the conclusion is reached that the ore minerals descended from the manto contemporaneous with the manto deposition. Ore-bearing (shrinkage) caves were also formed during the oxidation of sub-manto bodies. The bulk of the production in the last 125 meters of the Erupcion section was from the deep-ore.

Sideline Nuevo Mundo Cave Section.-- The Sideline Fault marks a general change in the character of the main ore body. South of the fault, the manto is wide and thin. The caves are low with a smooth, continuous hanging wall. Sub-manto ore occurs with increasing importance as the Sideline fault is approached. North of the fault, the larger caves are irregular in shape and size, the mantos are thicker and sub-manto ore predominates.

The section bounded by the Sideline fault on the south and the Nuevo Mundo fault on the north is the most complicated area of the mine. The mineralized area is roughly triangular in shape. The width decreases from 100 meters near the Sideline fault to 50 meters near the Nuevo Mundo fracture zone. During the development, the Sideline fault was crossed, and extraction proceeded in a section which appeared to be a direct extension of the Erupcion manto. This ore body had a width of 40 meters and decreased from a thickness of 5 meters in the west to a thin hilo in the east. A gone of N 15 degrees W fractures with a small upward displacement of the west block, marks the western side of this stope. A barren-cave system was exposed just west of the N 15 degrees W fractures which bound this manto on the east.

Before reaching the Nuevo Mundo fracture zone, a cave was exposed in the raised block and was thought to be another barren-cave. Exploration work soon proved that the supposedly small barren-cave was in reality a part of the great system of caves that extended both north and south of the point of penetration. To the south, the caves ascended along the bedding to the Side-line Fracture zone. The cave first penetrated was the Monte Blanco cave. Drilling thru the chaotic limestone and secondary calcitic covering of the floor of this cave disclosed the largest bodies of ore in the mine. The connected cave system from the Monte Blanco to the Sideline Fault is the largest discovered in the district.

The Cueva en Linea, del Coyote, las Leones, las Leonitas and del Monte Blanco (See Plate No. 3) lie between the Sideline and Nuevo Mundo faults. Intersecting systems of N 15 degrees W and N-E fissures are well marked in the roof of the caves. A huge thickness of limestone blocks cover the thick loose manto ore on the floor of the caves.

Altho the manto and hilo ore was thicker than any before worked, they are less prominent than the large sub-manto ore bodies beneath the mantos or occasionally to one side of the manto area. In two places, the sub-manto bodies extend a few meters into the Angela limestone. The Cueva las Leonitas is a notable example of rich ore occurring in one of the deep caves. It bounds the Cueva de Linea on the west.

The west part of the triangular area has no extension south of the Sideline fault. In the northern portion, as the Nuevo Mundo fault is approached, both the manto and sub-manto ore contain much more zinc and iron. The increase in the zinc and iron content is probably the result of leaching of the deep-ore body, together with enrichment with the oxidized zinc and iron. The total length of this section is 200 meters and the area has yielded the largest tonnage extracted to date from any unit of equal length.

Nuevo Mundo-Long Tom Section.-- The succeeding section north of the Monte Blanco cave is bordered on the south by the Nuevo Mundo fault and on the north by the San Luis fault. The section is 170 meters long and may be considered in two parts. The Nuevo Mundo cave forms the southern segment; the Long Tom, the associated Cueva la Cruz, and the 5-14 cave constitute the northern part of the section.

Displacements, from a few inches to a maximum of 50 feet, are observed on the Nuevo Mundo Fault. The faulting was normal, (See Plate No. 3).

The main ore body north of the Nuevo Mundo fault steps to the west. The ore body exhibited the same feature at the Side-line fault and it will be found repeated as the succeeding fractured zones are crossed.

North of the Nuevo Mundo fault is the ore-bearing cave with the same name. It has a very irregular roof, well blocked or jointed by intersecting fissures. The cave is over 150 feet in height. The ore on the floor is in places covered to a thickness of almost 100 feet by a chaotic accumulation of huge limestone blocks. The cave is over 300 feet wide and 500 feet long. Near the back of the cave thin hilos extend out in both walls. The primary body in this section was apparently wide and thin. The thin, loose ferruginous ore surrounded the huge limestone boulders which fell from the roof of the cave during the oxidation period.

Sub-manto ore bodies are found associated with the Nuevo Mundo fault zone at the intersection with N-S fissures and one large body occurs beneath the center section of the cave associated with a N-S fissure. A <u>barren-cave</u>, beneath the manto near the Nuevo Mundo fault, contains a heterogeneous deposit of angular limestone fragments and low grade iron, lead and zinc ore. Apparently the collapse of the thin limestone shell separating the manto from the barren-cave allowed the material to tumble or wash into the latter.

The northern end of the Nuevo Mundo cave descends abruptly and connects with the long, narrow tortuous Long Tom cave. This ore-bearing cave has a N-S length of 100 meters and an average width of 20 meters. The actual length of the cave is considerably increased by the zigzag course followed from the Nuevo Mundo cave to the San Luis fault. The first 25 meters trend due north, thence 85 degrees W, a distance of 40 meters, and then again assumes a N-S trend, a distance of 75 meters to the San Luis fault. The Cueva la Cruz connects with the Long Tom cave about 75 meters south of the San Luis fault. This cave extends 30 meters to the west and contains very rich, thick-bedded ore in the floor. The Long Tom cave in contrast to the Nuevo Mundo, contained a thick manto of high grade ore with a relatively thin cover of limestone boulders. The hilos are prominent, especially in the east wall where along prominent fractures it attains a thickness permitting extraction of zones as far as 50 meters away from the cave.

The manto thickness is almost constant from the Nuevo Mundo cave to within 30 meters of the San Luis fault. The ore in the final 30 meters of the cave decreases rapidly in thickness and is well leached.

The sub-manto ore is generally directly beneath the manto and is associated with N 10 degrees W fissures. The 5-14 cave, however, is an important exception. It connects with the Long Tom hilo near the eastern limit. This sub-manto ore body lying east of the Long Tom manto also follows a N 10 degrees W trend. The small size of the opening into the 5-14 cave and the fact that the associated ore above the cave is only an hilo shows that the large quantity of ore within the cave can not have been derived from this hilo by mechanical movement during oxidation, but must have been originally deposited as a sub-manto body. Deposition of the primary <u>sub-manto</u> ore contemporaneous with the manto ore will be discussed shortly. The back of the cave is just above the manto horizon and the floor 50 meters deeper. The ore of the 5-14 cave was very irregular in grade, varying from a high grade lead ore to a low grade ferruginous zinc ore. The ore body at a distance of 50 meters below the main manto assumes the manto form and appears to be one. However, it apparently ends. Other bodies of sub-manto ore expand at this horizon indicating that it is a <u>favorable horizon</u> for replacement. Farther to the north a second important continuous manto may be found at this stratigraphic position, or the upper manto may traverse the bedding, viz chimney and again develop a manto upon reaching this lower section of the Los Lamentos limestone. The Long Tom cave from the La Cruz to the San Luis fault has sub-manto ore bodies directly beneath the manto associated with a prominent N 10 degrees W fracture zone.

Barren-caves, with or without secondary material, are associated with the manto and hilos. The manto rapidly decreases in thickness and grade of ore as the San Luis fault is approached. The Long Tom cave similarly decreases in height and size near the fault. In the fracture zone it suddenly expands to form the Hojas de Plata cave.

<u>The Hojas de Plata Section</u>.-- The Hojas de Plata (leaves of silver) cave is rather narrow, the width varying from 10-20 meters. It is the most northern of the known large ore-bearing caves. The

height of the cave decreases from a maximum of 40 meters near the San Luis fault to a minimum of 5 meters near the Sonora-Vanadium fracture zone. Likewise, the thickness of the chaotic limestone covering decreases from a maximum in the south to a minimum in the north. The total length of the section is 110 meters. The general trend of the Hojas de Plata section is N 10 degrees W, coincident with the trend of an associated fracture zone. The dip of both the cave and manto increased in the vicinity of the Sonora-Vanadium fault zone, that is, they descend to a lower stratigraphic position in the formation.

The manto and the large sub-manto ore bodies are associated with a N 10 degree W ore channel. The manto increases in thickness and grades to the north.

The hilos are thin, high grade, well marked and somewhat above the level of the manto. Both east and west of the cave the hilos show small displacements along fissures N 10-15 degrees W. The hilos at the intersection of N 10 degrees W fissures with E-W fracture zones expand to form small, commercial bodies of high grade ore. The hilos are limited in lateral extent. In general, the thickness and extent of the hilos appears to be related to the manto. If the manto is thick and narrow, the hilos are usually small and thin; and if the manto is thin and wide, the hilos are usually very thin and extend great distances away from the cave. However, the above statement does not necessarily indicate a constant cross-sectional area of the ore body as held by Prescott.[1]

1. Prescott, Basil E.&M.J.--Vol. 122, No. 7, August 14, 1926.

A barren-cave system is associated with the southern 40 meters of the Hojas de Plata section. These deep, barren-caves or water-courses, sometimes contain small irregular bodies of secondary ferruginous ore.

Farther north in the section, the manto is underlain by a sub-manto ore channel associated with the N 10 degrees W fractures that rapidly increases in thickness near the Sonora-Vanadium fault zone. The northern boundary of the Hojas de Plata section is the southern boundary of the N 65 degrees W fracture zone known as the Sonora-Vanadium fault zone.

The sub-manto ore underlying the northern part of the Hojas de Plata manto was very ferruginous. These bodies extended to the contact of the Angela limestone. The ore occurred in very irregular stopes and the grade was erratic. The greatest depth obtained by the sub-manto ore bodies was near the Sonora-Vanadium Fault zone where the N 10 degrees W fractures that govern the trend of the Hojas de Plata section intersect the N 65 degrees W fractures of the fault zone.

Several small caves containing high-grade ore were encountered where the hilos were prospected from the main manto. This leads to the assumption that other small ore-bearing caves may be found by following the hilos outward from the ore body, especially where they are intersected by the cross-fractures.

The northern limit of the Hojas de Plata cave is marked by a limestone wall. Ore was found north of the fault at a depth of 25 meters below the level of the manto in the Hojas de Plata cave. This ore was different in character and occurrence from the manto ore.

Sonora-Vanadium Section.-- The ore bodies within the wide N 65 degrees W fracture zone, north of the Hojas de Plata cave, will be referred to as the Sonora-Vanadium section. An extension of the large manto of the Hojas de Plata section, N 10 degrees W, has not been found, and there is apparently no north extension of sub-manto ore to connect with the mantos south of the fault.

The sub-manto ore encountered in the Sonora-Vanadium zone was first thought to be the chimney feeder of the main manto. The ore bodies terminated when the Angela limestone was reached. Development revealed ore north of the fault and indicated that the ore body had again stepped to the west. However, the large bodies disclosed by recent work in the Sonora-Vanadium zone shows a general change in trend; apparently paralleling the fault zone. The longitudinal cross-section illustrates the regular continuation of the manto ore through this section (Plate No.3).

The main ore body may continue to follow the trend of the fault zone; may leave the zone and again assume the general N 10 degrees W trend followed by the ore body south of the zone; or may descend within the zone as a chimney. The fracture zone certainly offered a favorable area to expect a chimney. Later the main ore body was found to cross the northern boundary of the fracture zone and to continue as a manto. The large caves found to the south are not developed north of the Sonora-Vanadium fault zone. This lack of large caves suggests a fluctuating ground water level.

The deposit while traversing the Sonora-Vanadium fracture zone was characterized by vanadates and molybdates as important ore minerals. These minerals are irregular in their distribution but seem to be confined to the fracture zone. The possible explanation of this concentration of vanadium and molybdenum in this area will be discussed under "Ore Genesis." At the time of this study, no important bodies of vanadium-molybdenum ore had been found north of the Sonora-Vanadium fault zone.

The most important occurrence of the vanadates and molybdates was within an area designated by Ira B. Joralemon as the Vanadium Channel, which occurs within the wide Sonora Vanadium fault zone. Some of the finest specimens of vanadates and molybdates in the world have been collected in this area.

The ore body reaches the present water level as it crosses the Sonora-Vanadium section. This probably represents a temporary level in which case the oxidized ore may extend to a considerable depth below the present water table. However, if the vanadium-molybdenum minerals are the result of concentration and deposition at the water table, primary ore may exist within a short distance from the lowest workings at the present time.

BERRENDA MANTO

The Berrenda ore body outcrops at the surface and was at first believed to be a second manto. Later work indicates that it is a branch or off shoot of the main Erupcion-Ahumada deposit. The triangular shaped fractured area previously referred to as the "A" Fissure zone, which forms the northern limit of the Gypsum section, has apparently acted as the feeder for the Berrenda manto. Should this be true, it was mineralized thru the "A" Fissure zone within the favorable horizon and the Berrenda section may be assumed to connect with the main manto in the vicinity of the "A" Fissure section. Apparently the mineral bearing solutions followed 2 divergent paths westward from the main manto. These channels mark the two sides of the triangular "A" fissure zone. The northern fractures apparently formed the principal ore channel, the one in which a connection thru a commercial body may be expected. Between the limits of the diverging "A" fissure zone the Berrenda manto has an ir-regular course for 100 meters in an east-west direction. The ore averages about 4 meters in thickness and varies in width from 5 to 50 meters. It thickens to about 6 meters and widens where the manto is intersected by N 30 degrees W fractures. Except in the path of the feeding fissures the ore body pinches to the north. Hilos are prominent on the north side of the manto and almost absent in the south wall. The Berrenda manto was one of the first discoveries of the district. The character of the ore is similar to the main manto.

0-30 ORE BODY

The 0-30 ore body is a thin manto lying about 200 meters west of the main Erupcion-Ahumada manto. This body is referred to as the West Manto on the plan and section. (See Plate No. 3). It is badly faulted compared to the Erupcion-Ahumada deposit. The general trend is N 15-25 degrees W, that is, parallel to the

Erupcion-Ahumada ore body. The known length of this manto was less than 200 meters at the time of this examination. The north end of the manto was terminated by a fault. The greater part of this manto is not of a commercial width and thickness, altho at one point where it is cut by an E-W fracture a maximum width of 50 meters occurs. Many of the short sections between the cross-fractures yielded only a thin seam of galena and iron oxide. The ore is of a higher grade than the Erupcion-Ahumada ore body. When the ore-trend is cut by the cross-fractures, vugs and small caves are found.

A number of transverse tunnels from the main workings cut a strong mineralized fracture zone that is a direct projection of the known ore trend of the West manto. Undoubtedly, there is an extension of this manto and it may reasonably be assumed that the cross-section will increase to the north toward its source. The evidence indicates that this manto will not unite with the Erupcion-Ahumada ore body south of the Sonora-Vanadium fault zone. Its attitude within, or north of the fault zone, is purely hypothetical. The Sonora-Vanadium fault zone may be the site of the junction of the two mantos, or the west manto may be deflected to the northwest as is the case of the Erupcion-Ahumada ore trend.

PROSPECTS

Outside of the main mineralized zone, the Erupcion-Ahumada ore channel, several strongly mineralized outcrops occur. The most important of these is the 'Mexico', a prospect near the southern end of the range (Plate No. 2). A small tonnage of ore had been shipped from this prospect before the ore was lost by faulting.

FRACTURE SYSTEMS

The fissures encountered underground in the Los Lamentos district may be classified into 4 groups or systems which have definite characteristics and influence upon the control of the mineralization. In the following table the fissures are grouped according to their strike and arranged progressively according to age.

GROUP	CLASS	ECONOMIC CHARACTERISTICS
1.	N 10 W to N 20 W	Most important group. Apparently tensional cracks along axis of gentle anticlinal fold. Governs trend of the mineralization. Channels for the deep-ore. Channels for dry-cave systems. Post-mineral movement.
2.	E - W	Principal fault planes. Caused spreading of the ofe body. Responsible for great irregularity in cross section. Pre-and post-mineral movement.
3.	N 65 W	Governs in part the trend of the ore channel (Sonora-Vanadium). Prominent fault planes. Principal channel for the vanadium-molybdenum mineralization. Pre-and post-mineral movement.
4.	N 50 E	Important group of cross fractures. Main feeder to Berrenda manto belongs to this class. Pre-and post-mineral movement.

GROUP I

The N 10 degrees - 20 degrees W fissures are the oldest pre-mineral fractures of the district. They are apparently tensional cracks developed most prominently along the crest of broad anticlinal folds. The age of the fracturing is, therefore, contemporaneous with the folding. The Erupcion-Ahumada ore body followed the fractured crest of such a fold. Certain beds were less resistible to fracturing than adjacent sections. Strong tensional fissures developed during deformation may be very prominent in brittle strata and inconspicuous in an adjacent series. A combination of well fractured ground with a deformed structure, governs the location of manto deposits.

The Los Lamentos formation was well fractured by a zone of N 10-20 degrees W tensional fissures that are rather inconspicuous in the underlying Angela limestone and the overlying San Vicente formation. The fracturing is also prominent at several horizons in the Bufa formation.

This fracture system apparently was not subjected to pre-mineral movement, altho, some minor post-mineral movement is observed. The fissures also acted as channels for the deposition of the sub-manto ore. Heavily mineralized fractures at several places have the appearance of veins. This led some investigators to believe the ore bearing solutions ascended in these fissures.

During oxidation, this fracture system was especially prominent and governed location and trend of the barren-caves.

The side walls of the ore-bearing caves are usually coincident with a fracture plane of this group. The fractures have been greatly enlarged by the oxidizing solutions.

GROUP II

The East-West breaks form the second group in order of time. They include the most prominent fractures of the mineral zone. The movement, altho small, in some cases was enough to displace certain very favorable beds thru which mineral-bearing solutions ascended. When the fractured zones were encountered, the solutions were dammed for a time and this caused a spreading of the ore body behind the fault. The ore bodies on opposite sides of a fault may then show a radical change in cross-section.

The fractures were subjected to both pre-mineral and post-mineral movements. The most important of these E-W fractures encountered during mining are discussed briefly below.

"A" Fissure Zone

The north side of the triangular shaped 'A' Fissure zone is formed by a strong fracture of the E-W system, while the southern margin is formed by a strong N 50 degrees E fracture. A very small pre-mineral displacement occurs along the E-W fracture. Some of the fractures of the E-W system apparently were channels for the ore-bearing solutions responsible for the Berrenda manto. However, the N 50 degrees E fissure along the southern margin of the zone formed the most important channel.

This triangular shaped area contained the lowest grade ore found in the mine. Apparently the entire zone was subjected to almost complete leaching during oxidation.

Sideline Fault.

The Sideline fault zone belongs to the E-W system and has a strike of N 80 degrees W with a dip of 75 degrees south. The fault is not a single break but a strong zone of fissures and slips, having a total width from 10 to 20 feet. The fissures are well marked with a secondary iron and zinc filling. The total throw found within the developed area varies from 20 to 50 feet with a down throw to the north making the Sideline fault of the reverse order. There is evidence of both pre-mineral and post-mineral movements. It marks a character change in the main ore-channel. South, from the fault to the surface, the ore body is essentially an ideal manto with sub-manto ore developed only in the vicinity of the fault, while to the north, the bulk of the mineralization occurs in the so-called sub-manto ore bodies. A regular hanging wall with low insignificent ore bearing caves occur south of the fault while a magnificent system of ore-bearing caves is developed to the north. Some of the caves are over 200 feet in height.

The ore-bearing solutions came from the north in the favorable manto horizon and encountered a barrier at the fault zone. This temporarily retarded the advance of the solutions and widened the depositional area in back of the fault. The solutions finally broke thru the fault zone east (100 meters) of the general axis of the section north of the fault. This stepping east of the ore body when encountering a prominent shear zone is repeated several times north of the Sideline fault.

A remarkable feature is the increase of the silver content in a wide zone extending 50 meters both north and south of the fault. The sheared area was apparently the channel for hypogene silver enrichment of the ore in a zone parallel to the fault.

<u>Nuevo Mundo Fault</u>

The Nuevo Mundo fault (Plate No. 3) has a general strike of N 80 degrees E with an almost vertical dip. The faulting is normal with the south block showing a maximum displacement of 50 feet. In contrast to the Sideline fault zone, the Nuevo Mundo fault is a large, partly cavernous, fissure from 5 to 15 feet wide. The fissure is partly filled with cellular and black oxides of iron, oxidized zinc, and limestone fragments. The Nuevo Mundo fault like the Sideline zone was a barrier to ascending ore-bearing solutions and caused a spreading of the deposit below the fault. The manto stepped to the east, 75 meters, before penetrating the break.

Stopes in the vicinity of the fault contain an unusually high content of iron and zinc. Evidently the fault was a prominent channel for oxidizing solutions which, in the vicinity of the fault, deposited secondary material which locally lowered the grade of the ore.

<u>San Luis Fault.</u>

The San Luis fault, 165 meters north of the Nuevo Mundo fault, is another prominent E-W fracture. Altho no appreciable movement was encountered within the developed ground, the fracture was an important pre-mineral break. This break marks a decided change in the cross section of the ore body analogous to the previously discussed transverse fracture zones.

Deposition of primary ore in the fracture extended to the Angela limestone. Several sub-manto ore bodies are associated with and extend north from the fault. The ore-bearing solutions, responsible for the sub-manto ore bodies connected with the fault, undoubtedly descended from the manto thru the fracture.

The San Luis fault has a general strike of N 80 degrees E with a dip of 80 degrees south. East of the ore channel, it intersects the Sonora-Vanadium zone. The triangular block between the two faults is upthrown with respect to the adjacent blocks. The movement on the San Luis was much less than on the Sonora-Vanadium fault.

GROUP III

The N 65 degrees W fissures form the third group in order of time. Underground fissures of this group have been observed cutting the E-W and the N 10-20 degrees W system. Pre-and post-mineral movements of small magnitude occur. The manto trend within the Sonora-Vanadium zone and several sub-manto ore bodies are guided by the fractures of this system.

Sonora-Vanadium Fracture Zone.

The Sonora-Vanadium fracture zone is an intricately fractured area, about 60 meters wide, has a general strike of N 60-65 degrees W and an average dip of 75 degrees north. The fracture zone, wherever encountered underground within the Los Lamentos limestone is well mineralized. It cuts both the San Luis and Nuevo Mundo fracture zones east of the main ore body. On the surface, the fault can be traced for over 1500 meters by the calcite filled stringers. This fault zone should not be confused with the Sonora Overthrust Fault already described by Ransome.

The fracture zone was first believed to be the site of a change from a manto to a vertical pipe or chimney. The prediction by Ransome that the ore body would traverse the zone without notable displacement or change in form is substantiated by later work. Continued work showed the typical manto form maintaining a N 65 degrees W trend within the fault zone. It is very probable that the ore channel north of the fracture zone has a general N 15 degrees W trend.

The most noteworthy feature of the Sonora-Vanadium zone is the high vanadium and molybdenum content. Outside of the zone, vanadium and molybdenum rarely occur.

GROUP IV

The N 50 degrees E fissure system is the fourth in order of time. It is a group that has been the site of both pre- and post-mineral movements of small magnitude. Intersecting fractures with the N 10-20 degrees W system are favorable sites for small pipe feeders to sub-manto ore bodies.

A fractured zone of this group is the main channel for ore-bearing solutions responsible for the Berrenda manto. It also forms the southern boundary of the 'A' Fissure Zone section.

MINERALOGICAL CHARACTER OF THE ORES

The district yields a remarkable suite of oxidized lead minerals, and, in a number of both the common and rare species, an exceptionally fine crystallization is developed. Several of the less common minerals which are ordinarily museum specimens, are the chief constituents of the ore in some parts of the deposits.

Recently Dr. W. F. Foshag, of the United States National Museum, collected in the Los Lamentos district, and his paper on the mineralogy is in preparation. In view of this work, the mineralogy will be only briefly treated.

The following list includes the determined ore and gangue minerals:

- LIST OF MINERALS -

<u>Native Minerals</u>
Sulphur
Silver
<u>Calcium Minerals</u>
Calcite
Dolomite
Ankerite
Gypsum
<u>Lead Minerals</u>
Galena
Anglesite
Cerussite
Wulfenite
Vanadinite
Descloizite
Pyromorphite
Plumbojarosite
<u>Zinc Minerals</u>
Sphalerite
Hydrozincite
Willemite
Goslarite

<u>Iron Minerals</u>
Pyrite
Hematite
Limonite
Gothite
Jarosite
Siderite

<u>Copper Minerals</u>
Malachite
Azurite
Brochantite (?)

Three primary sulphides, namely galena, pyrite,and sphalerite have been identified. Distant from the main oxidized ore channel, occasional disseminations of sulphides have been found in dense unaltered limestone. Pyrite also occurs sparsely disseminated thruout certain limestone beds, but this is a common feature of limestone and is apparently unrelated to the mineralization. Galena is the only sulphide abundant in the ore-channel. It is found as residual kernels protected from complete oxidation by anglesite and in a massive state in unoxidized, thin, tight hilos flanking the manto ore bodies.

Anglesite, cerussite,and plumbojarosite are the chief lead ore minerals. Almost pure beds of anglesite and cerussite (sand carbonate) occur in the oxidized ore. The anglesite may be associated with the gypsum beds and in some cases, abundant enough to warrant profitable extraction of gypsum layers. Both anglesite and cerussite are found enclosing residual galena. Plumbojarosite is an important lead ore mineral, especially associated with the iron oxide layers.

The oxidized ore occurs in layers with iron oxide minerals forming the major part of the volume, or as a heterogeneous mixture of iron and lead minerals. The low grade iron oxide bands containing lead carbonate can be roughly separated from the higher grade bands of lead minerals. The most abundant iron minerals are hematite, limonite, gothite, and jarosite. The different oxides can usually be identified underground without any trouble. Occurrence of siderite is rare and confined to very tight fractures. The iron oxide minerals form the bulk of the oxidized ore; have been deposited in the numerous fractures traversing the mineralized zone; and have filtered into the porous crystalline dolomite.

Hydrozincite, willemite, and goslarite are the three identified oxidized zinc minerals. The hydrozincite generally occurs in white, chalky masses along the floor of the oxidized ore bodies, or as fissure fillings above and below the oxidized ore. It is easily recognized from the invariable earthy texture. Willemite occurs as minute crystals usually yellowish-brown in color; while the third oxidized zinc mineral, goslarite, is found as incrustations in fissures below the ore bodies. In comparison with the lead and iron minerals, the zinc minerals form only a small portion of the oxidized ore. The greater part of the zinc has been carried away by circulating waters during oxidation, unless the ratio of sphalerite to the lead and to the pyrite of the primary ore was much less than generally believed by other investigators.

The character of the hilos and the absence of large bodies of zinc ore below the mantos and sub-manto ore bodies, leads the writer to conclude the sphalerite was present in only subordinate amounts in the primary ore.

Copper minerals are very rare. Malachite, azurite and brochantite (?) are the only three minerals identified, and occur occasionally on gypsum crystals.

During this work, native silver was found as wires and flat plates associated with the copper minerals and gypsum. The presence of silver in larger quantities was expected but in only one stope was any silver mineral megascopically identified.

The chief calcium minerals related to the mineralization are calcite, dolomite, ankerite, and gypsum. The calcitic incrustation of the open fractures, ore-bearing and barren-caves, has already been discussed. Ankerite has been identified as coarsely crystalline masses in the recrystallized beds of limestone and dolomite.

One of the notable features of the district is the large amount of gypsum and free sulphur found in the upper part of the mine. The explanation of their genesis is a problem for future study. Undoubtedly, the reaction of the sulphate oxidizing solutions, as a result of the oxidation of the pyrite, reacted with the limestone with which it came in contact, to form calcium sulphate. The calcium sulphate was partly carried away by circulation and partly deposited within the ore body as gypsum. The associated bodies of sulphur are supposed to have been derived by the reduction of the gypsum. Gypsum layers are usually found within the bedded oxidized ore thruout the mine and form large deposits in the barren-caves.

Wulfenite, vanadinite, descloizite, and pyromorphite are confined to the Sonora-Vanadium Fracture Zone. The occurrence of these minerals outside of the zone is so rare that it becomes a curiosity. The wulfenite and vanadinite are so abundant at and below the water table that they form the chief ore minerals. The consensus of opinion is that the molybdenum and vanadium have been leached from the galena and migrated downward during oxidation and deposited as secondary minerals at the water table. However, the restriction of these minerals to a definite zone within the Sonora-Vanadium fracture zone suggests a relationship between the two and it may be that this occurrence represents a second stage of mineralization with the Sonora-Vanadium zone as the channel. Descloizite and pyromorphite are occasionally found outside the Sonora-Vanadium zone.

OXIDATION AND DOLOMITIZATION

The Erupcion-Ahumada ore body has been almost completely oxidized. Only sections of the thin hilos flanking the mantos remain unaltered. The original character of the deposit has been almost obliterated by the process.

The primary sulphide body consisted chiefly of galena and pyrite with a subordinate amount of sphalerite. These occur as a metasomatic replacement in the limestone without prior development of cavernous openings. Residual sulphides found in the hilos, and investigation of the primary mantos of the Santa Eulalia district, permits inference as to the character of the original sulphide body. The original sulphide ore body was apparently a rather confined and complete replacement instead of a body of limestone thru which the sulphides were distributed in a more or less disseminated condition.

Surface solutions subsequently attacked the sulphides with the action accelerated by generation of acid during the oxidation of the pyrite. In addition to changing the sulphides to sulphates the resulting acid solutions readily attacked the limestone. A large amount of the iron sulphate, which resulted from the first step of the oxidation process, was carried away and redeposited as oxides in the innumerable fissures and open fractures traversing the mineral zone, while the bulk of the iron was deposited as oxides beneath the original sulphide bodies. The acid solutions generated during oxidation attacked the limestone beneath the ore body and the removal of the limestone was accompanied by subsidence of the manto section.

Zinc was very susceptible to oxidation and transportation. A large quantity of the zinc was transported by the circulating waters and deposited with the iron in the innumerable fissures and fractured zones. The large bodies of oxidized zinc ore found beneath the mantos of several districts in Mexico is not a character of the Los Lamentos deposits. Here the oxidized zinc commonly occurs above the ore bodies in the open fractures, suggestive of artesian conditions during oxidation. The zinc minerals, chiefly willemite and hydrozincite, are found along the limestone footwall of the oxidized ore bodies and sometimes along the hanging wall, or as irregular layers within the bedded oxidized ore. A study of the ores strongly suggests that the original sulphide ratio of the iron and lead to the zinc was much greater than found in the sulphide zones of some of the other manto districts. There is no evidence of large bodies of zinc ore occurring beneath or near the lead ore bodies in the area.

At first the galena readily reacted with the acid oxidizing solutions but the action was later retarded by a coating of the oxidation products. The galena is replaced by stable pseudomorphs of anglesite and cerussite. Residual galena (often erroneously refered to as secondary galena) is found from the lowest workings of the mine to the surface.

The acid solutions changed large quantities of the limestone to calcium sulphate and in this condition the calcium was either removed by the circulating waters or redeposited in the form of gypsum within the ore bodies and caves.

ORE-BEARING AND BARREN-CAVES

Cave Formation

The acids generated during oxidation vigorously attacked any limestone with which they came in contact. In this manner fissures were corroded forming open crevices and large volumes of limestone were removed by reaction and the circulation from beneath the original sulphide ore bodies. The latter was accompanied by contemporaneous subsidence of the ore leaving an open space above. The removal of limestone marking the beginning of a cave was later expedited by collapse which continued until the roof became a stable arch. Caves above oxidized ore have been called shrinkage-caves. This is a misnomer as there was no shrinkage during oxidation. In fact the oxidized material necessitates a greater space than the original body.

The contact of the lowered ore body with the limestone walls is very sharp and many investigators have interpreted this as indicative of pre-mineral cave formation. A study of a district where the mantos occur in both an oxidized and primary state disproves this hypothesis. Even in an oxidized district where hilos are well developed, as in this locality, a pre-mineral cave system theory is unfounded.

The circulation of the acid oxidizing solutions dissolved enormous amounts of limestone in the main circulating channels. Cavernous openings were formed in beds that were more susceptible to corrosion than others. This removal of limestone was analogous to the action accompanying the oxidation of the ore bodies and marked the beginning of a cave. Collapse of the unsupported hanging wall and removal of the fallen limestone blocks formed large caves herein called barren-caves, the term implying absence of primary ore bodies. Secondary ore in barren-caves of this district is more common than usual. This is to be expected as they are parallel to the ore trend, while in other camps, the Santa Eulalia district for example, the caves follow fracture systems which traverse the trend of the ore bodies. The trend of barren-caves is indicative of the most open fracture system during the oxidation cycle. The fissures of this district governing the trend of the primary deposition was the most open system during oxidation.

The barren-caves occur either beneath or to one side of the main ore channel, or attain both positions. Where the caves occur under the main ore body, the shell of limestone separating the oxidized mantos from the barren-caves occasionally collapsed allowing heterogenous masses of oxidized ore and angular limestone fragments to fall into the cave. Oxidized material was often washed into the enlarged fractures and barren-caves. Caves containing mechanically deposited secondary material should not be confused with the sub-manto ore bodies.

Oxidation of sub-manto ore bodies is accompanied by cave formation analogous to those of the manto ore bodies. The caves, however, are much smaller. Several caves associated with the mantos attain a height of almost 200 feet. In general, the height of an ore-bearing cave is proportional to the thickness of the ore body.

Large blocks of limestone continued to fall from the roof of a cave, mixed with the following oxidation and formed a thick cover between the ore and the open cave. The last stage of the oxidation process was the formation of the calcitic shell within the ore-bearing caves, barren-caves and cavernous fissures. The inside of this shell is lined with beautiful calcite crystals.

FORMATION OF DOLOMITE

Local dolomitization of the limestone occurs in the vicinity of the ore bodies. The primary ore minerals apparently furnished enough magnesium to locally convert limestone to dolomite. However, whether the alteration of the limestone to dolomite thru the addition of magnesium took place during the primary deposition of the ore minerals or by magnesium leached from these minerals during oxidation, is a problem which has not been satisfactorily decided.

The dolomite usually occurs beneath and alongside of the oxidized ore with dense unaltered limestone above. It might be held that the collapse of the hanging wall during cave formation has obliterated the dolomitic shell which once inclosed the mineralization. The blocks covering or mixed with the ore, however, are not dolomitic. Field evidence and assay results from several hundred samples indicate the formation of dolomite during the oxidation of the ores.

The dolomite occurs only in a coarsely crystalline form. It is usually stained red by the addition of iron oxide. Where-ever the fracturing is well marked beneath an ore body the dolomite often extends to the bottom of the Los Lamentos formation. Zones of iron stained dolomitic limestone occasionally occur above an ore body in areas of intense fracturing. When fracturing is rather tight below an ore body no alteration or dolomitized limestone occurs. Therefore, while dolomitization is a rough indicator to the proximity of mineralized ground, it is by no means the proof of its existence.

Several hundred samples were taken at definite intervals from known ore bodies, both below and above, and at definite intervals in an exploratory area. These suites were analyzed for their dolomitic content. The assays were then plotted, together with the detailed geology, to determine whether dolomitic contours inclosing an ore body could be constructed. Where fracturing was intense, recrystallization of the limestone accompanied by the addition of magnesium was well marked. If, however, the beds were dense and unfractured the alteration of the limestone near an ore body was local. In porous beds strong zones of altered limestone likewise extend long distances laterally from an ore body.

ORIGIN OF THE ORE

The Erupcion-Ahumada ore channel has been almost completely oxidized to the bottom of the mine, so that it is necessary to infer the nature of the primary ore body from the character of the oxidized material and analogy to manto camps, where both primary and oxidized ore bodies occur.

The nearest intrusive rocks are the monzonitic porphyries of the El Gorrion Range, 45 kilometers west of Los Lamentos. This intrusion has metamorphosed the upturned limestone and is accompanied by a contact metamorphic mineralization. It is reasonable to assume then, that the Los Lamentos deposits were probably related to some deeply buried rock of monzonitic composition. We may infer, from our knowledge of other districts, that the manto will be found to have been fed from its lowest point by a chimney which in turn will probably pass thru a contact metamorphic zone. However, the deposit in depth may occur as a vein rather than a chimney. It is likely, however, that the mineralizers would follow the paths of least resistance from the igneous source to the ultimate manto deposit. When the mineralizing solutions reached the Los Lamentos limestone structural conditons caused them to leave the fissures or intersecting fissures and follow the bedding of the formation along the crest of a gentle, tho well fractured anticlinal fold. This horizon was very susceptible to metasomatism. The ore-bearing solutions were retarded by prominent cross fractured zones of small displacement causing a spreading of the deposit in back of the shear zones.

This feature is well shown on the plan of the ore bodies (Plate No. 3). Finally after breaking thru the fractured zones, the solutions, encountering an unrestricted course, continued to ascend. Thus south of a fault there is a sudden decrease in cross section of the deposit relative to the section north. Consequently a triangular shaped deposit was developed between prominent fracture zones with the apex toward the source of the ore-bearing solutions.

The primary deposit was probably a more or less complete, yet restricted, lenticular shaped replacement in a well fractured zone of certain beds.

The ore-bearing solutions descended from the manto horizon along fissures or intersecting fissures and by metasomatism produced the sub-manto ore bodies.

The primary deposit consisted chiefly of pyrite, galena and sphalerite with subordinate amounts of other minerals. The sphalerite was apparently less abundant than found in the sulphide mantos of the Santa Eulalia district.

The extent of oxidation, with the development of the great cave systems and the abundance of the iron oxides are more indicative of continuous massive sulphide bodies than of a disseminated deposit. The development of dolomitized limestone occurred by addition of magnesium probably made available thru leaching of magnesium-bearing primary minerals during oxidation. Areas of dolomitic limestone are well developed beneath the ore bodies. Indeed this latter hypothesis, in view of the erratic distribution of the dolomite, seems more logical than the general hypothesis supporting the formation of dolomite before or during the original mineralizing process.

The ore body in the Sonora-Vanadium fault zone is suggestive of two periods of mineralization--the earliest, the sulphide stage mentioned above and a later introduction of molybdenum and vanadium. It is more probable, however, that the molybdenum-vanadium zone is the result of concentration of leached material which migrated downward, was deposited and enriched at the water table during oxidation.

Migration of metallic and other constituents of the ore during oxidation was considerable. Segregation of oxidized zinc and iron minerals in fissures above and below the ore bodies and the hydrozincite lining along the bottom of the caves and ore bodies is indicative of migration. Duplication of mineral bands within the oxidized ore suggests that the high grade sulphides enclosed lenses of low grade disseminated sulphides or barren limestone which during oxidation was removed. This would account for a repetition of oxide bands observed in some sections of the mine. The primary mantos of the Santa Eulalia district often show two high grade sulphide mantos separated by a lense of low grade disseminated ore or barren limestone.

The ore-bearing caves and barren-caves were formed during oxidation. The sharp contact of the limestone walls with the oxidized ore is the result of the lowering of the manto from its original site during oxidation. The sharp contacts have been interpreted by some investigators as indicative of ore deposition following cave formation which, however, for the manto deposits of northern Mexico is erroneous.

There is a general decrease of the manto cross-section from the deepest workings to the surface. Likewise the sub-manto ore bodies, which in the lower part of the mine furnish the bulk of the tonnage, do not exist near the surface. (Plate No. 3). Altho a gradual decrease in cross section occurs upward from the source structural conditions control and cause radical changes in the general plan and cross-section of the ore body.

During the past few years there has been a general tendency on the part of certain investigators to minimize the importance of fracturing and structure in relation to manto deposits. The study in this district together with investigation of several of the most important manto deposits farther south in Mexico, has, the writer believes, accentuated rather than diminished the importance of these features in the control of metasomatism.

The origin of manto deposits will be treated in detail in the paper on the Santa Eulalia district where, because of the primary ore bodies more data is available for consideration of the genesis. The nature of the mineral bearing solutions is discussed and emphasis placed on a possible colloidal condition of the solutions. This possible origin of the ore bodies by colloidal solutions, if applicable to Santa Eulalia, would undoubtedly also be influential in the Los Lamentos district.

GEOLOGY AND ORE DEPOSITS

OF THE

SANTA EULALIA DISTRICT

Chihuahua, Mexico

by

J. WILFRED PATTERSON

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CONTENTS (con't.)

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INTRODUCTION

This is the second of a series of papers on the Manto Type Limestone Replacement Deposits of Northern Mexico. The practical questions cannot be answered until the data on which they depend are discussed. Comparison of this paper with earlier reports on the district brings out differences that are explained in part by the much extended mine development, and in part by more thorough field work.

The Santa Eulalia range is composed of gently folded Lower Comanchean sediments, overlain by a thick series of volcanic flows, tuffs, and conglomerates. The ore deposits lie within a slightly domed uplift in the middle part of the long, narrow Santa Eulalia range. The pre-mineral fracturing and folding, while scarcely perceptible, had a pronounced influence on the location of the deposits. Two classes of dikes were intruded following the close of the mineralization. Altho the ores are well zoned, no intrusion to which the deposits are genetically related has been found.

ACKNOWLEDGMENTS

The writer is indebted to Dr. L. D. Ricketts for making possible this study and for his suggestions and criticisms.

Especial thanks are due to Dr. F. L. Ransome of the California Institute of Technology who has supervised this work and critically discussed its problems. Thanks are also due to the Board of Trustees, Dr. John P. Buwalda, and Mr. Rene Engel of the California Institute of Technology.

The mine owners and operators of the district have aided the study by ready and courteous cooperation. Without exception, all facilities for underground work, maps, and assistance of various kinds were cheerfully furnished. Appreciative acknowledgment is made to Messrs. E. P. Ryan, Harlan A. Walker, and Chaunce Thornberg of the El Potosi Mining Company, S. A.

SITUATION

The Santa Eulalia mining district occupies the central part of a short, narrow mountain range of the same name, in the State of Chihuahua, Mexico. The northern part of the Santa Eulalia range, including the ore deposits lies within the political District of Iturbide. The southern part is in the District of Camargo--the boundary line extends east-west thru Picacho Oriental, the highest peak of the range. Santa Eulalia is one of the earlier, if not the earliest, known manto type limestone replacement deposit of Mexico. The mines have occupied a leading position in the world's silver production during the last 200 years.

The range lies at approximately 28 degrees 40 minutes north latitude, 105 degrees 50 minutes west longitude; about 15 miles east-southeast of Ciudad Chihuahua, capital of the State of Chihuahua. It is reached by rail (Figure 1) from El Paso, Texas over the National Railways of Mexico to Chihuahua City, 325 kilometers (approximately 202 miles). Two railroads and a fair automobile road connect Chihuahua City with the Mines. The narrow gauge electric tramway of the Potosi Mining Co. runs from Hacienda Robinson to the Company mill, 2 miles northwest of the town Real de la Santa Eulalia; thence to the Potosi mine at Santo Domingo, 3 miles east of Santa Eulalia. Hacienda Robinson is occupied by the general offices of the Potosi Mining Co., and was formerly the site of the Santa Eulalia Silver Mining Co's pan-amalgamation plant

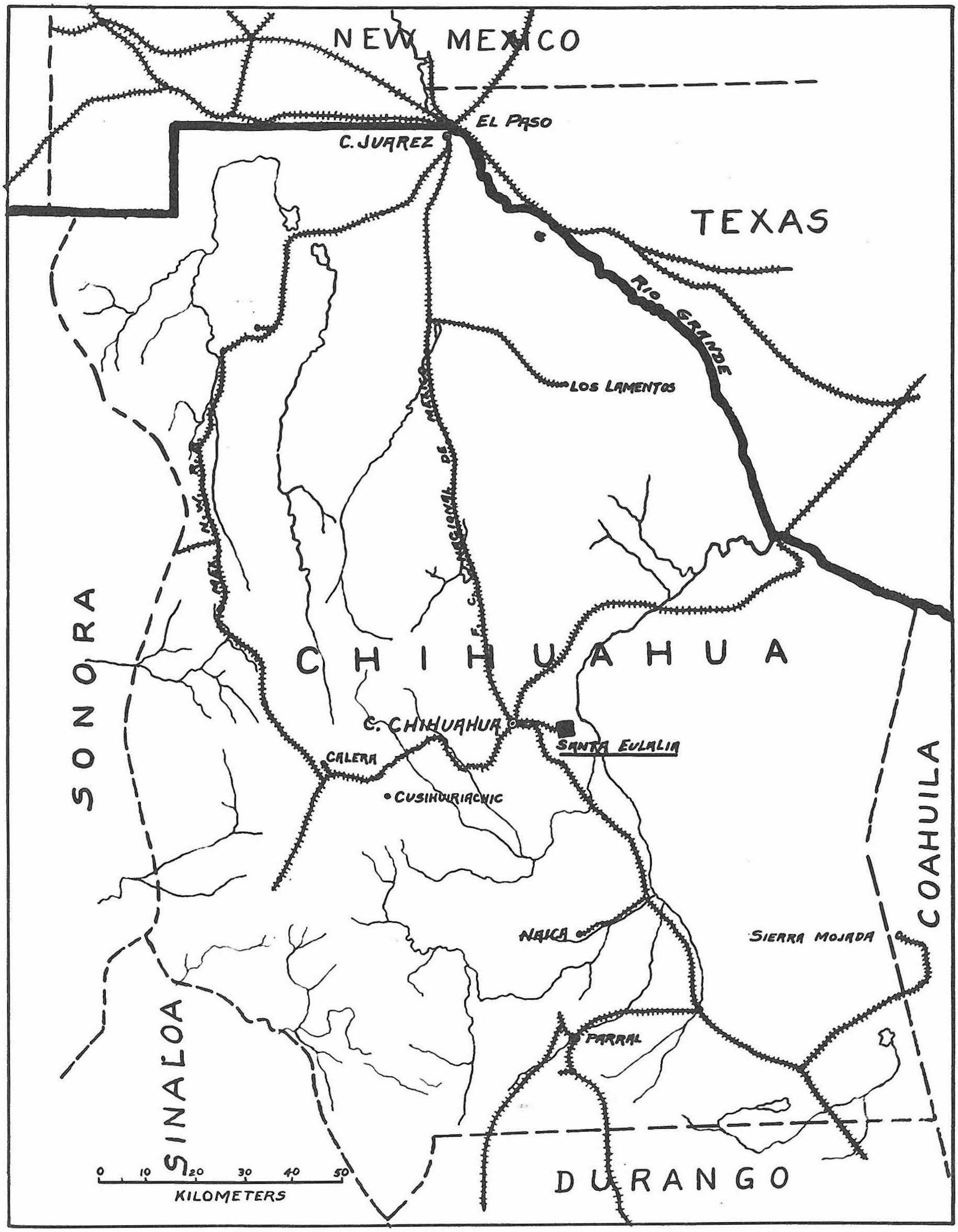


Figure 1. Index map showing the position of the Santa Eulalia district.

and smelter. Water for the town of Santo Domingo and the Potosi Mill is pumped from Hacienda Robinson.

The nearest United States territory is 93 miles northeast, where the Rio Conchos empties into the Rio Grande. The Los Lamentos district lies 220 kilometers (137 miles) due north of Santa Eulalia.

In addition to the electrified road of the Potosi Mining Co., the Ferrocarril Mineral de Chihuahua connects C. Chihuahua to the Puebla de Santa Eulalia. Here a connection is made by means of an aerial tramway to the northwestern part of the camp (Velardena Aerial Tram). The National Railways of Mexico have a spur to a point within 2 miles of Santa Eulalia where it connects with a second aerial tramway which runs into the southern and eastern part of the district (San Toy Aerial Tramway).

HISTORY

There are several contradictory legends concerning the early history of the district. According to Kimball,(1) Don Jesus Inocente Irigoyen of Cusihuiriachic, Chihuahua, a good antiquarian authority, states that the year of the discovery was 1591. One legend, which seems improbable, is that the discovery of the district preceded the Spanish Conquest.

Official records of the year 1705 place the date of discovery as 1703. This was 12 years after the founding of the Mission of Chihuahua. Should this date be accepted, the district is not ancient in the light of the history of Mexican mining.

Similarly, there is no consensus of opinion between authorities concerning the place of discovery. Some maintain that the first ore was found on the claim known at present as La Carlota, and that the earliest work was done on this claim and around the peak called the Picacho Oriental. This includes the San Antonio, Dolores, Ibera, Nueva Santa Sulalia, and Pagina denouncements which form the East Camp of Santa Eulalia. According to those favoring this ~~locality~~ legend, the larger deposits of the Santa Eulalia District that lie to the west and northwest were discovered after the founding of the Pueblo of Chihuahua Vieja.

Others maintain that the original discoveries were made in the northwestern part of the main mineral district near the canyon of Parcionera or Mina Vieja; and the deposits of

(1) Kimball, J. P.--Am. Jour. of Science, 2nd ser. Vol. xlix, pp. 161-175, (1870)

Mina Vieja, Parcionera, Aguada, Santa Rita, Santo Domingo, San Jose and the Dolores were the first to be worked. This view is supported by official records of production.

General Lew Wallace states, "The discovery of the silver was romantic; as the story runs, in the year 1700 or thereabouts, three fugitives from justice, hunted out of the Haciendas around Chihuahua, (itself then nothing better than a lively Catholic Mission), took refuge in the fastness of what is now known as Santa Eulalia. Shifting from mountain to mountain, they took up quarters finally in a tremendous ravine (now called the Canyon de Parcionera) in which there was a natural tanque of water, and where they could remain with prudent conduct perfectly safe. One day the Senor Padre in the city, through a friendly Indian, received a message from the outlaws to the effect that if he would absolve them and obtain their pardon from the official authorities, they would put him in a way of getting enough silver to build a Cathedral in New Spain. The offer was accepted, they were absolved and pardoned, the mines were opened; their fame went rapidly through the country, miners flocked from all parts of Chihuahua, traders followed, of course. The mission became a city of 70,000 inhabitants, a growth and prosperity attributed to Santa Eulalia alone." (1)

Other writers have expanded the tale and claim that 3 fugitives discovered the metal on a cold night when it was necessary to maintain an extremely hot fire, which was built

(1) Wallace, Gen. Lew--Harper's Monthly, Nov. 1867

near a bank in the canyon and during the night the heat of the fire melted the silver and caused it to flow. The next day the fugitives sent word to Chihuahua that the largest Cathedral in New Spain would be built in return for their pardon.

To digress a moment, the Cathedral of Ciudad Chihuahua, while not the largest in Mexico, is a magnificent monument to the Mines of Santa Eulalia. The cost of the Cathedral has been stated by authorities to be between $750,000 to $1,000,000 and it is said to have been erected without the use of a derrick. A mound of earth permitted the mules and burros to drag the building stones to the places required.

A tax, to pay for the construction of the Cathedral of Chihuahua, was collected over a period of 62 years and amounted to $800,000. This represented a tax of one real per marc of silver coined, (12½ cents per $8.00 Ag or 1.5% of the yield). Some claim the period for collection of this tax to have been 12-14 years; but official records place the collection over a period of 62 years.

The Cathedral has suffered during the turbulent periods of Mexican history. Many of the decorative figures have been shot away, and the Cathedral bells are cracked. At different places, the edifice has served as a wall for executions and shows a surface pitted by rifle bullets. Despite the ravages of civil strife, the Cathedral remains one of the most beautiful architectural monuments in Mexico. The Cathedral of Santa Eulalia is also a monument to the productivity of the district.

An old legend, handed down from the antiguas, is that the eastern part of the camp was first discovered by Spanish prospectors. They came over from the Placeras de Santo Domingo on the Conchos River. The iron-stained, volcanic-capped Picacho Oriental was supposed to have been the guide to this area. Their first camp was made near a spring on the denouncement known as the Chihuahua Vieja. This became the site for the first Puebla de Santa Eulalia, the ruins of which remain standing. The Chiribel mine is supposed to have been the first worked, but was soon followed by work on the Carlota claim.

It is problematical which of these accounts is authentic. The most reliable historians favor the discovery date as 1703; and the place of discovery as somewhere in the northern part of the west camp.

In the year of 1791, the district had a population of 6000. It supported over 160 reduction establishments, 188 smelting furnaces of the crude hornos type, 65 cupelling furnaces, and 63 beneficios. Also at this time over 20 small furnaces operated in Chihuahua City.

Kimball records that during the period from 1705-1737, the district officially produced 6,583,000 marcs, or an average of $1,938,903 oz. Ag per annum. During the first 86 years, 1705-1791, the royal tax (King's quinto or fifth) was deducted from a production valued at $112,000,000. The untaxed or stolen ore has been estimated to be at least 1/5-1/3 more; so this period can be reasonably assumed to have produced metal worth

$150,000,000. According to the estimates of the more conservative writers, total production to the present time has been in excess of $500,000,000.

The close of the 18th century marked a period of depression as a result of successive raids by the Apache Indians. The camp was abandoned almost overnight. During the first ten years of the 19th century, attempts were made to operate the mines, but failed, owing to the timidity of the inhabitants who did not care to live in the district. Mining practically ceased during, and following, the revolt of Mexico from Spanish rule.

After the secession from Spain, intermittent Apache raids, lack of leaders, as well as money, made it impossible to resume full operation. A small production was made, however, during this period.

Most of the silver produced by the Mexicans and the Spaniards was extracted from the old Parcionera, Bustillos, Mina Vieja, San Juan, Santo Domingo, San Jose, Santa Rita, Rosario, Galdeano, and Las Animas mines. The mines were operated from surface openings, or Boca Minas, using, from the Mexican miners point of view, the acme of perfection in transportation, that is, burros for removing ore to the surface.

American capital began to exploit Mexico during the last quarter of the 19th century, and interest was revived in the Santa Eulalia district.

About the year 1880, an American, John R. Robinson, was granted a concession from the government for himself and for

Kidder, Peabody & Co. The concession, 15 miles long and 5 miles wide, covered the whole district and most of the range. Those interested, then organized the Santa Eulalia Silver Mining Co.

The company built a small pan-amalgamation plant in the canyon of the Mina Vieja, near the Parcionera mine. Shortage of water caused the abandonment of this plant. A larger mill was constructed near the city of Chihuahua where water was abundant. The site was called Hacienda Robinson.

In the year 1882, the Mexican Central Railroad was completed to Chihuahua City. The same year, Robinson constructed a narrow gauge road from the Hacienda to the Mines.

Most of the production at this time came from the Santo Domingo and Galdeano mines. The increased lead content in the ores, mined at this time, caused the company to abandon pan-amalgamation and return to smelting process. Furnaces, therefore, were constructed at the Hacienda.

Mr. Robinson had obtained the Santa Eulalia mining rights as a tunnel concession, and it was held by doing a small amount of work each year. His company mined a large tonnage; but in 1891, the company sold out to John W. Shaw, and Oliver Paine. These men formed the Chihuahua Mining Co. Shortly after, the Mexican government revised the mining laws, one of which established a tax on each pertenencia of mineral ground. The Company, under Mr. Shaw's direction, soon dropped a greater part of the property under the concession.

Reasons stated for Mr. Shaw's release of land were high taxes, and the belief that, with the railroad competition in the district would not be countenanced. Thus but a few small plots, namely, the Santo Domingo, Santa Rita, and the Zubiate were retained by the Company. The released land was thrown open in 1894.

It was assumed that the richest land of the district had been retained, but the premature release proved a grave mistake for the company. It stimulated, however, a revival of the district. The released ground was immediately denounced, and fresh capital acted to open new ore bodies in both the old and new mines. Later, the Chihuahua Mining Co., thru necessity, purchased the Potosi Claim, one they had earlier voluntarily released. This claim proved to be the largest producer of the district; and according to present indications, it will probably continue in this role.

Three large companies either own or control thru lease practically all of the district. The Velardena-Mina Vieja ore bodies (West Mantos) that extend north from the Potosi ground are under the control of the American Smelting and Refining Company. They also control the Parcionera, several small claims beyond the limits of the West Mantos, and a greater part of the East Camp. During the past 2 years the company has constructed a mill at the Chihuahua smelter at Avalos, a few miles east of Chihuahua. Here the tin ores from the East Camp are treated.

The Potosi Mining Co., subsidiary of the Howe Sound Co., controls the Chihuahua Mining Co. They own the Potosi claim and a few outlying plots including the Coronel-Zubiate and Santa Rita, and have the Buena Tierra Mining Co. properties under lease.

The Peñoles Co. (Cia. Minera de Peñoles, S.A.), the American Metals Co's Mexican subsidiary, control the rest of the district with the exception of a few small privately owned claims. The properties of the Peñoles Co. cover an enormous stretch of ground, including the East Mantos, or the Bustillos-Galdeano-Manto, the Central manto and a number of properties situated in the southern end of the district.

Mining methods of extreme contrast are used and vary from the crude ancient, to the most up to date practice.

Before construction of the railroads the oxidized ore was packed to Durango on burros and there used to smelt the siliceous ores of that State.

REGIONAL TOPOGRAPHY

The rocks of the Mesa Central may be classified under two large groups by a line roughly drawn through El Paso, Chihuahua City, Durango, Zacatacas, San Luis Potosi, and Pachucha. East West of this line, rocks of sedimentary origin prevail. These are usually a thick series of Mesozoic limestones and shales. The limestones are of Comanchean or Lower Cretaceous age and attain a great thickness in Mexico. The Los Lamentos district (220 kilometers to the north) is situated near the western margin of the outcropping sedimentaries.

The prevailing rocks west of the forementioned line are of volcanic origin and consist mainly of flows, tuffs, and breccias of Tertiary age. They have been poured out over the calcareous Cretaceous beds. The Santa Eulalia district lies within this group, very near its eastern boundary.

LOCAL TOPOGRAPHY

The Santa Eulalia range is a long, narrow, volcanic capped, anticlinal fold rising rather abruptly above a broad plain that forms the floor of the Mesa Central. Bold cliff faces, that characterize the ranges in the eastern part of the Mesa Central where limestones prevail, are generally absent in the Santa Eulalia Range. The Cretaceous limestone core of the Santa Eulalia is covered by a series of tuffaceous rocks. The limestones are exposed in the mineralized district in deeply incised canyons.

The range has a general NE-SW trend with a length of approximately 20 miles, and a width of 7 miles. It lies between the champaign valleys of the Rio Conchos on the east and the Rio Tabalopa on the west. The Conchos river valley is over 25 miles wide in the vicinity of the Santa Eulalia range. It is bounded by the Choreras mountains on the east and the Santa Eulalia mountains on the west. The Choreras mountains form the most western outlier of uncapped Cretaceous limestone in the area while Santa Eulalia's have over 1500 feet of tuffaceous material covering the limestone core of the range.

The broad valley plain of the Tabalopa river borders the Santa Eulalia range on the west, where, after a span of 12 miles, the plain gives way to rather prominent, isolated peaks which rise to form the eastern limits of the city of Chihuahua. The peaks are composed chiefly of flows, tuffs, breccias, and conglomerates. A large part of the building stone used in the city of Chihuahua is quarried there.

The mineral district of Santa Eulalia is embraced within an elliptical shaped domical uplift, called the Sierra de la Santa Eulalia. This irregular eminence is approximately 4 miles wide at the elevation of the mines, and the longer axis has a length of almost 7 miles. The highest peaks in the range are in the district and rise to over 2000 feet above the surrounding plains. They have an elevation of over 7000 feet above sea level.

The uplift of the Sierra de la Santa Eulalia was accompanied by faulting and fissuring which controlled erosion. This is observed in the present topographic features. The concordance between ridges and peaks within the district leads one to suspect that during uplift, faulting was the major force. Apparently the Sierra de la Santa Eulalia is an uplifted slightly domed fault block. Erosion has cut deep into the mountain, removing the capping in places and incising deep gorges into the limestone. Using the marginal fault zones as channels, erosion has cut deeply so that at present the Sierra de la Santa Eulalia stands almost isolated from the limbs of the range. The canyons radiate from the center of the mountain; and the Real de la Santa Eulalia, the municipality of the district, is located in one of the canyons on the northwest edge of the mountain.

A detailed account of the stratigraphy and structure (presented later) will show that the folding while comparatively simple has developed structural features of importance as to the location and course followed by the ore bodies.

An arid climate and vegetation prevail. The rainfall is meager, being confined to a few summer thunder showers and an occasional winter rain with sometimes a light fall of snow. Springs are almost unknown in the range and the mines are practically dry.

CRETACEOUS ROCKS OF THE NORTHERN PART OF THE MEXICAN CORDILLERAN PROVINCE

The formations of Cretaceous age in Mexico are imperfectly known. Most of the data available is from reconnaissance work done by European geologists. In these records, correlations have been made with the Cretaceous of Europe using the European nomenclature.

The correlations made from paleontological evidence appear uncertain and will only be justified when more detailed work in the thick Cretaceous strata of Mexico is accomplished.

It appears more logical in the study of the Mexican Cretaceous to correlate the formations with the adjacent beds in southern Texas.

Altho the excellence of the recent paper of Bose and Cavins[1] is recognized, European nomenclature will not be used in this study.

A. R. Fletcher[2] recently presented a tentative correlation of certain manto deposits to stratigraphic horizons based on the paper of Bose and Cavins.

(1) Bose, Emil & Cavins, O. A.--The Cretaceous and Tertiary of Southern Texas & Northern Mexico--University of Texas Bull., No. 2748, Dec. 22, 1927.
This Bulletin uses the European nomenclature which for this work is undesirable because of the great thickness attained by the Albian stage in Mexico and Southern Texas.

(2) Fletcher, A. R.--Mexico's Lead-Silver Manto Deposits and their Origin. E.& M.J. Vol. 127-No. 13 Mar. 30, 1929

Table No. 1 is a correlation of typical Texas formations with the European stages of the Cretaceous.

The Albian stage of the Mesocretaceous covers almost the entire Comanchean section exposed in parts of Northern Mexico and Texas. Use of the American terminology makes it possible to give closer stratigraphic definition to the vertical range of the favorable manto sections.

Facies and characteristic features of the different formations of the Cretaceous naturally change somewhat when traced into Mexico from southern Texas; so it is preferable to adapt a separate nomenclature for Northern Mexico. Table No. 2 shows a tentative classification of the formations for Northern Mexico. Later work will undoubtedly introduce evidence that will enable us to divide the broader classification into smaller units.

TABLE NO. 1

CORRELATION OF THE TEXAS CRETACEOUS WITH THE STAGES OF THE EUROPEAN CRETACEOUS SECTION.

	Southwest U.S. Terminology			European Terminology	Modified for Mexico
		Texas Formations		European Stages	
		(Escondido beds)		Maestrichtian	
		Navarro beds		Campanian	
		Taylor marls		Santonian	
Upper Cretaceous			U.		Supra-Cretaceous
		Austin chalk	M.		
			L.	Coniacian	
			U.	Turonian	
		Eagle Ford sh.			
			L.	Cenomanian	
		Bufa l.s.			
	Washita Division	Del Rio clay			
		Georgetown beds	U.		
			L.		
		Edwards l.s.			Meso-Cretaceous
	Fredericksburg Division	Comanche Peak l.s.			
		Walnut clays		Albian	
Comanchean		Paluxy form.			
		Glen Rose form			
	Trinity Division	Travis Peak form.		Aptian (Upper)	
		Trinity sands ?		Aptian (Lower)	
		missing		Barremian	
		"		Hauterivian	
		"		Valanginian	Infra-Cretaceous
		"		Berriasian	

TABLE NO. 2

GENERALIZED DIVISION OF THE COMANCHEAN SERIES FOR NORTHERN PART OF MEXICAN PLATEAU PROVINCE

		Northern Mexico	Texas Equivalent	
		Triste ls.		
		Buena Suerte ls.	Del Rio clays	
	WASHITA DIVISION	Tlaxcala ls.		
		Sonora ls.		
				Albian
COMANCHEAN SERIES	FREDERICKS-BURG DIVISION	Bufa ls. (Upper Fossil ls.)	Comanche Peak ls.	
		Intermediate ls. (Fetid ls.)	Glen Rose	
	TRINITY DIVISION			
		Los Lamentos ls. (Lower Fossil ls.)	Travis Peak?	Aptian
		Black ls. (Blue ls.)	Trinity sands?	
		Unconformity(?)		
JURASSIC		Quartzite shales & Sandstones		

The three part division of the formations of the Cretaceous of Mexico is shown in the following table.

TABLE NO. 3

CRETACEOUS OF MEXICO

Age	Character
Upper Cretaceous	Upper part largely sandstones and shales. Lower part largely shales, marls and intercalated limestones.
Washita division	
Comanchean Fredericksburg division	Great thickness of massive to thin bedded limestone with intercalations of shales.
Trinity division	
?Lower Trinity or Jurassic	Thin bedded limestone with intercalations of shales near top with transition to shales and sands in lower section.

Only a few sections definitely identified as Jurassic in age are known in the northern part of the Mexican Cordilleran province, altho the sandstones, shales, and quartzites underlying the thick Comanchean Black limestone have been reported to be of Jurassic age.

Formations conformably underlying the Black limestone in Chihuahua are definitely younger than Jurassic (the Infra-Cretaceous of Mexico). However, the lower sandstones and shales of this section may be of Jurassic age. There is a marked predominance of shales and calcareous shales near the top of the section. The thickness of this member varies from a few feet to several thousand feet in thickness. The formation grades into the overlying limestone which forms the basal (?) member of the Trinity Division of the Comanchean.

COMANCHEAN SERIES

TRINITY DIVISION

Black Limestone

The lowest member of the Trinity Division encountered in northern Mexico is the Black limestone. This formation has been called and sometimes reported as the Blue Limestone and Ransome [1] in the Los Lamentos District has given it a local name, the Angela Limestone. For a broad use, the term Black Limestone, indicative of the prevailing color, is preferable. It averages over 2500 feet in thickness. The maximum thickness is unknown and in some regions the formation is not recognized. The section increases in thickness from the northwest to the southeast. The Texas equivalent of the upper part of this formation is probably the Trinity sands which have been correlated with the Lower Aptian of the European classification.

(1) From a paper on the Geology and Ore Deposits of the Los Lamentos Range by F. L. Ransome and J. W. Patterson.

The limestone is rather thin bedded, very dark grayish-blue to almost black in color and near the top contains a paucity of fossils. Frequently beds of chert nodules occur near the top of the formation. The cherts vary from thin bands of small round nodules to thick beds of scraggly forms. Locally cherts become very abundant. The rock is rather dense in character and usually breaks with a semi-conchoidal fracture. A chiselled or fluted effect is characteristic of the weathering. The outcrops vary from a bluish-white to a purple color. Until recently this limestone was supposed to be unfavorable for replacement deposits.

Los Lamentos Limestone

The Los Lamentos has locally been called the Lower Fossil and Caprina limestone. Since the fossils are not constant in abundance or kind over the northern section and as all the formations are more or less fossiliferous, the term is not applicable.

The type section is in the Los Lamentos Range and was described by Ransome. It conformably overlies the Black limestone strata. It is the main manto horizon of the Los Lamentos district as well as one of the most favorable zones for replacement lead-zinc-silver deposits thruout the Plateau region.

The formation will be tentatively placed as the Mexican equivalent of the Travis Peak and Lower Glen Rose formations of Texas, which have been correlated as probably equivalent to the Upper Aptian stage of Europe.

The Los Lamentos limestone, in general, is a thick-bedded almost massive formation with rather indefinite bedding planes. It is fossiliferous thruout with characteristic large irregularly coiled pelecypods (Caprina) and corals. The fossils are replaced with coarsely crystalline calcite which allows unsatisfactory parting.

The color varies from light to dark gray. It weathers in buff colored cliffs, spotted with the white calcite fossil fillings. It is dense but not as indurated as the Black limestone. The maximum observed thickness is 600 feet. Topographically it is a cliff-forming member. Being thinner bedded than the Bufa limestone, which is also a cliff-forming member, the prominance of the Bufa cliffs permit a quick differentiation between the two. Chert nodules are rare.

Intermediate Limestone

Conformably overlying the Los Lamentos is an impure shaly member called the Intermediate limestone. A formaninifera, '*Orbitolina texana*, Roemer', (one of the Glen Rose formation index fossils), is very abundant in the extreme northern part of the Mesa Central, and rather scarce south of Chihuahua City, Chihuahua. Its stratigraphic occurrence and physical character permit a correlation over the entire north and central parts of the Plateau. It is the equivalent of the upper Glen Rose beds of Texas which have been placed as a parallel to the base of the European Albian stage. The top of the formation is used here tentatively as the division between the Trinity Division and the Fredericksburg Division of the Comanchean Series.

The formation is for the most part dark gray and thin bedded, with an almost a shaly lamination which becomes more noticeable on weathering. Occasionally it is rather pure and resembles the Black limestone. Compared to the strata below and above, it is quite free of large fossils. Locally it has been called 'Fetid Limestone', because of the fetid-odor obtained when the rock is struck. It is not a character peculiar to the limestone in this case for several formations give the same odor when broken. Bands of round to scraggly cherts are locally abundant.

As it is less resistant than the cliff-forming members it separates and produces a distinct profile. In regions where the two cliff-forming members occur the Intermediate limestone may be readily identified as a dividing member separating the cliff-forming rocks.

FREDERICKSBURG DIVISION

Bufa Limestone

The Bufa strata conformably overlies the Intermediate limestone. It is the predominant formation throughout the Plateau province. The formation is tentatively regarded as covering the whole Fredericksburg division and may be in part Upper Trinity and the Lower Washita. From paleontological evidence the formation may later be broken into several units. Evidence of stratigraphic breaks have not been discovered in the series.

The term Bufa is widely used throughout Mexico to express a very prominent outcrop, bluff, or cliff. Within the Plateau province the high precipitous limestone cliffs, especially in the eastern part of the Mesa Central, are almost without exception a physiographic expression of the Bufa.

The limestone resembles the Los Lamentos formation. It is fossiliferous throughout, and has facies where very fossiliferous zones occur. It is massive, some beds reaching a thickness of 100 feet and has a general thickness of 10-20 feet between bedding planes. Usually a transitional contact occurs with the Intermediate limestone.

As only the lower part of the formation remains, in most localities a maximum thickness is speculative. The thickness, however, is over 3000 feet. The Comanche Peak limestone of Texas is equivalent to the middle part of the Bufa formation, and this corresponds to a part of the Albian stage in Europe. Fossil identification indicates the formation covers the whole of the Fredericksburg Division.

WASHITA DIVISION

Sonora Limestone

Overlying the Bufa formation is a series which physically appear to be a repetition of the Trinity and Fredericksburg formations. Paleontological evidence proves the series to be definitely younger and belonging to the Washita Division of the Comanchean.

The exact relationship of the lowest member, the Sonora limestone, of the group to the Bufa is unknown at present. Future work will probably show whether the contact is conformable or not. Identified occurrences of the Sonora formation leads to the conclusion that the upper part of the Bufa formation was soft and subject to rapid erosion. The effect is a common occurrence of two parallel tilted ranges separated by a narrow valley; an erosional expression rather than a structural occurrence. This type of topography is common in the northeastern part of Chihuahua; until recently, the parallel ranges were thought to be a repetition of the lower Comanchean Series thru faulting. Ransome was the first to recognize the distinction of the upper formations from the Lower Comanchean Series, and to assign them formation names. A. A. Stoyanow from paleontological determinations placed this series in the Washita division, thus corroborating the field evidence.

The Sonora limestone is the lowest formation of the Upper Comanchean series and physically resembles the Black limestone of the Trinity Division. It is, as a rule, thin-bedded, blue-gray, rather dense, breaks with a semi-conchoidal fracture, and contains only a few fossils. The faunal determinations place it definitely above the Bufa limestone formation. It is over 500 feet thick with an unknown maximum depth. The type locality for the Sonora, named by Ransome, is in the Los Lamentos district where it is overthrust upon the lower part of the Bufa limestone.

Tlaxcala Limestone

The Tlaxcala limestone, lithologically, is similar to the Los Lamentos formation. It is fossiliferous, rather massive, weathers yellowish-brown and gives a cliff-like topographic expression. It lies conformably upon the Sonora formation. The maximum known thickness is over 500 feet. The type locality is in the Los Lamentos range.

Buena Suerte Limestone

A rather soft thin-bedded fossiliferous limestone known in the Los Lamentos district as the Buena Suerte limestone conformably overlies the Tlaxcala formation. In some characters the formation is lithologically comparable to the Intermediate limestone of the Trinity Division. Paleontologically, it is the equivalent to the Del Rio formation of Texas which is middle Washita in age, and, therefore, a part of the upper Albian of Europe.

The bedding is shallow, less than 4 feet thick and the prevailing color a dark gray. Generally it is purer than the Intermediate limestone. The rock gives a fetid-odor when struck with a hammer.

Triste Limestone

The cliff-forming limestone which conformably overlies the Buena Suerte formation is the youngest known member of the great Comanchean series. The name Triste limestone is applied to this formation. Where remnants occur the topographic feature is cliff-like as a result of its compact nature and thick bedding. Lithologically, it appears similar to the Bufa limestone. It is very fossiliferous and the total thickness is unknown.

CONCLUSION

1. The Lower Cretaceous section of Northern Mexico is a continuation of the Texas Comanchean.
2. Correlation of the formation in Northern Mexico with the Texas Comanchean permits a more restricted assignment of ore-bearing horizons than is possible with the European system.

Table 4 shows a group of manto deposits correlated with both the European and American sections.

TABLE NO. 4

DISTRICT	STATE	A.R. FLETCHER[(1)] CLASSIFICATION	J.V. PATTERSON CLASSIFICATION
Sierra de Ramires	Coah.	Aptian	* Trinity (Los Lamentos form.)
Conception del Oro	Zac.	Aptian	* " " " "
Reforma	Coah.	Aptian	* " " " "
Vic. Of Monterey	N.Leon	Aptian	* " " " "
Higueras	Coah.	Aptian	* " " " "
Norias de Bajan	"	Albian	* Fredericksburg (Bufa form.)
Santa Elena	"	Albian	* " " "
Musquiz	"	Albian	* " " "
Sierra Mojada	"	Albian**	Trinity (Los Lamentos form.)
Mapimi	Dgo.		" " " "
Naica	Chih.		" " " "
Los Lamentos	"		" " " "
Santa Eulalia	"		" Los Lamentos and Black l.s. form. & Fredericksburg (Bufa form.)

* by correlation
** paleontologically placed in Trinity Division.

(1) Fletcher, A. R.--Mexico's Lead-Silver Manto Deposits and their Origin. E. & M. J. Vol. 127, No. 13 March 30, 1929, pp. 509-513.

CRETACEOUS ROCKS OF THE SANTA EULALIA DISTRICT

The oldest rocks found in the Santa Eulalia district are Lower Comanchean sediments. They range from massive to thin-bedded, pure to argillaceous, dense to porous limestones.

The formations maintain a general attitude of N 60 degrees W with dips varying from 5 to 10 degrees. Minor flextures or warps occur and it is only by most detailed study that these are observed. The obscure folds are very important for they govern the trend of the manto ore bodies.

Following deposition of the limestones the region was uplifted and subjected to deep erosion. The formations above, together with the greater part of the Bufa have been eroded away. The topography preceding deposition of the capping rocks attained the approximate features observed today in the uncapped limestone ranges that stud the eastern part of the Mesa Central. Dissection has carved deep narrow arroyos in the uplifted masses.

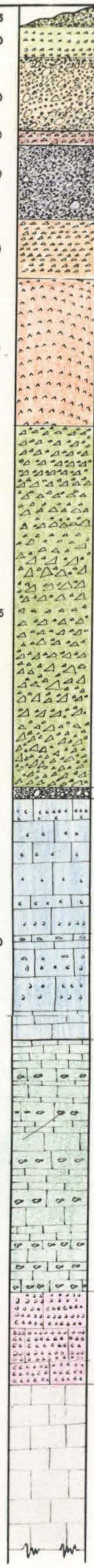
Figure No. 2 shows a columnar section of the formations of the Santa Eulalia District.

BLACK LIMESTONE FORMATION

The Black limestone is the oldest exposed formation. Its upper part and probably the whole deposit belongs to the Trinity Division of the Comanchean. Its known thickness in the Santa Eulalia district is 1500 feet. The Black limestone is found thruout the northern part of the Plateau province, and is generally

Figure 2.

COLUMNAR SECTION SANTA EULALIA DIS'T.



THICKNESS IN METERS		
0 - 15	FOURTH CONGLOMERATE	Original thickness unknown. Erosional remnants occur in but few places. Similar in composition to the 3rd CONGLOMERATE
±20	FOURTH TUFF	Fine grained. Greenish base. Andesitic groundmass. Angular fragments rather small.
10 - 50	THIRD CONGLOMERATE	Composed chiefly of rounded Cret. l.s. boulders and pebbles, and large amount of volcanic material. Considerably eroded after deposition. Secondary cementation.
±10	THIRD TUFF	A variation of 2nd. Conglomerate. Excess of tuffaceous material.
±50	SECOND CONGLOMERATE	Principally well rounded Cret. l.s. boulders. Large amount of tuffaceous material. Some angular tuff fragments, both rhyolitic and andesitic. Cementation by tuffaceous material. Subjected to erosion preceeding deposition of THIRD TUFF.
0 - 40	SECOND TUFF	Fine grained tuff. Brownish. Cheifly andesitic with minor amounts of rhyolitic material. Deposition on uneven surface. Remnants restricted in area.
0 - 100	RHYOLITE FLOW	Flow covered whole area. Flowed over very uneven surface, indicating sharp erosion preceeding deposition. Thickness variable, usually very thin. Considerably eroded before deposition of SECOND TUFF.
210 - 225	LOWER TUFF	Chiefly a rhyolitic tuff. Angular fragments show material unworn by water action. Evidently a very rapid accumulation. Cheifly laid down on the old Cret. l.s. surface. The basal conglomerate is usually missing. Tuff highly silicified. Has appearance of a flow.
0 - 6	LOWER CONGLOMERATE	Composed of rounded l.s. boulders. Found only in old arroyos.
25 - 200	BUFA FORMATION (UPPER FOSSIL LIMESTONE)	Rather thick bedded fossiliferous Cretaceous limestone. Known as BUFA LIMESTONE in many parts of Mexico. Cliff-forming limestone. Usually light colored. Youngest limestone found in district, carved by erosion before the Tertiary volcanic-conglomeratic capping deposited. Upper Manto Horizon
150 - 170	INTERMEDIATE LIMESTONE (FETID LIMESTONE)	Fairly thin bedded limestone. Beds with scraggly chert nodules. Dark gray. Some of the darker beds very impure, almost shaly, give a fetid oder when struck. Usually no important orebodies occur in this horizon.
50 - 60	LOS LAMENTOS (LOWER FOSSIL LIMESTONE)	Very fossiliferous limestone. Light colored, semi-crystallized and slightly dolomitized in certain localities. Has been one of the most productive ore horizons in the past. The Upper and Lower Fossil Limestones were in the past believed to be the only MANTO horizons of commercial importance.
+350	BLACK LIMESTONE (BLUE LIMESTONE)	Dark bedded limestone. Thickness unknown in district. Fossils scanty. Contains numerous favorable MANTO horizons. Rather dense and contains numerous beds of chert nodules.

considered as unfavorable for manto deposits.

The Potosi Mining Company refused to accept this view and by development exposed numerous large mantos of primary ore in the Black limestone. This discovery will undoubtedly lead to extensive prospecting of the formation in other mines in the district; also in other manto regions.

The limestone is, in general, rather thin-bedded, blue-gray to very dark gray, dense to finely crystalline, and contains few fossils. The bedding planes vary from a strong shaly parting to an indefinite crinkly type of stylolite, commonly referred to as 'wigglies'.

Numerous zones of cherts occur ranging from small,round shapes to large,scraggly forms. Chert bands show a marked continuity over the district, and may be used as marker-beds when comparing different sections.

Marker-bed U-9 designates the contact of the Black limestone with the Los Lamentos. Eleven marker beds have proved to be favorable manto horizons below the top of the Black limestone.

The mantos in the Black formation are in a primary state, and,therefore, utilized for study. Altho no manto has been worked comparable in length to the famous East and West Mantos of the district, ore bodies of considerable magnitude have been studied that follow all the principles applicable to oxidized mantos.

The Black limestone is quite pure, and not dolomitized to an appreciable extent. A bed will rarely assay over 2.5% MgO. The silica content fluctuates. The formation is argillaceous in the northern part of the district increasing in purity toward the southern part of the Potosi mine. In a proved favorable horizon the most important loci for ore deposits occur at the intersection of the N-S fissures in one or both of the traverse systems. When a new ore body is encountered the horizon is determined and designated and a diamond drilling program inaugurated to intersect the calculated projections of the horizon with other intersection fissures.

Sections or horizons most favorable in the Black limestone are U-11, 12, 14, 15, 16, 17, 18, and 19. A recently proved marker bed, U-20, is rapidly becoming one of the most important ore-bearing horizons in the district. The marker beds are located in the geologic shaft sections. (Figures No. 3, 4, and 5).

One contributing cause for the well developed fissures is the compact nature of the Black limestone which fractures easily. Limestones having texture less compact would be less subject to fissuring during deformation.

A medium dense, semi-crystallized, highly fossiliferous, light gray limestone delimits the uppermost margin of the Black formation.

The upper part of the Black formation is probably equivalent in age to the Trinity and Travis formations of Texas.

Figure 3.

GEOLOGIC SECTION OF SANTO DOMINGO SHAFT A.S.&R.CO.

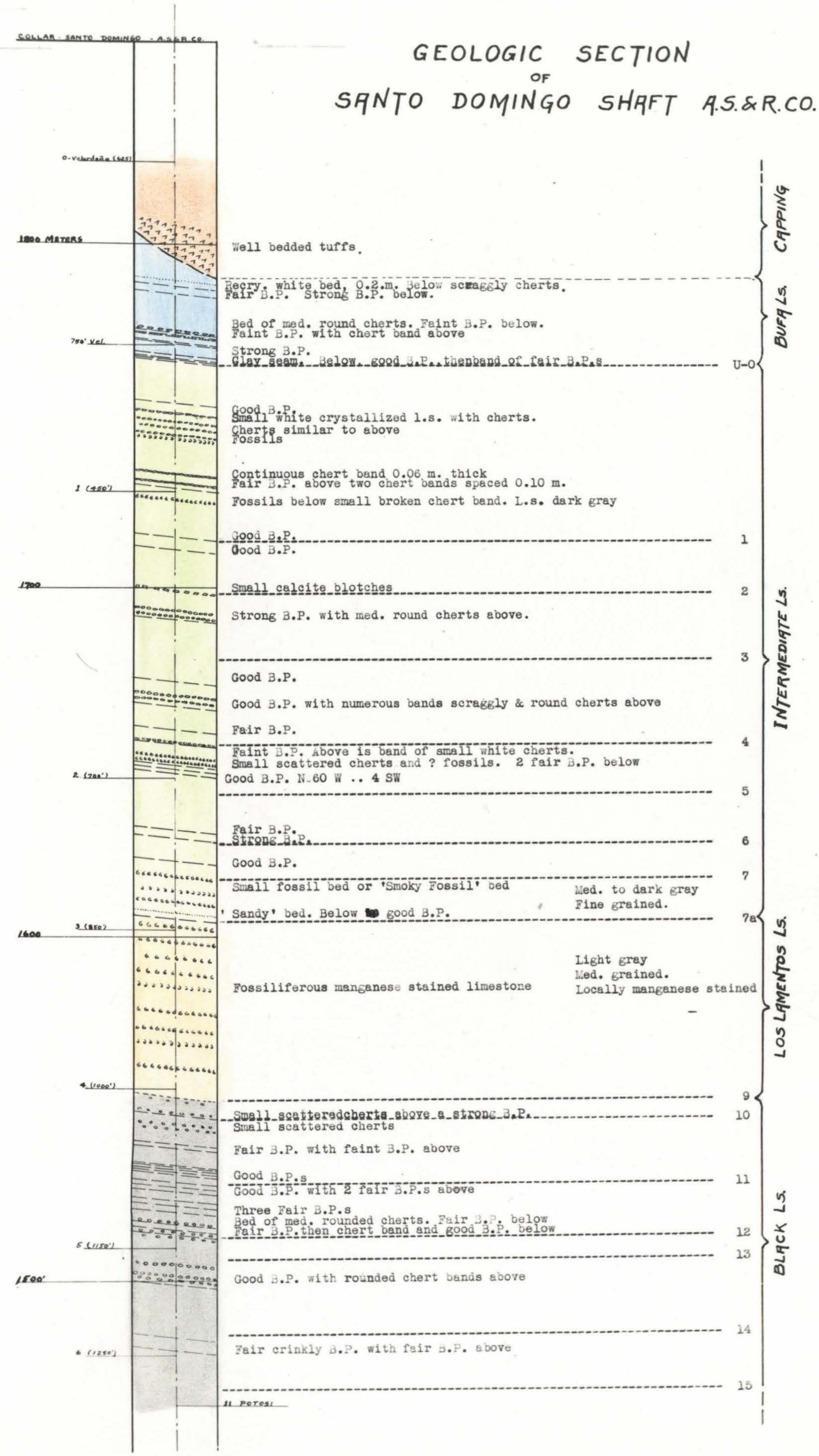
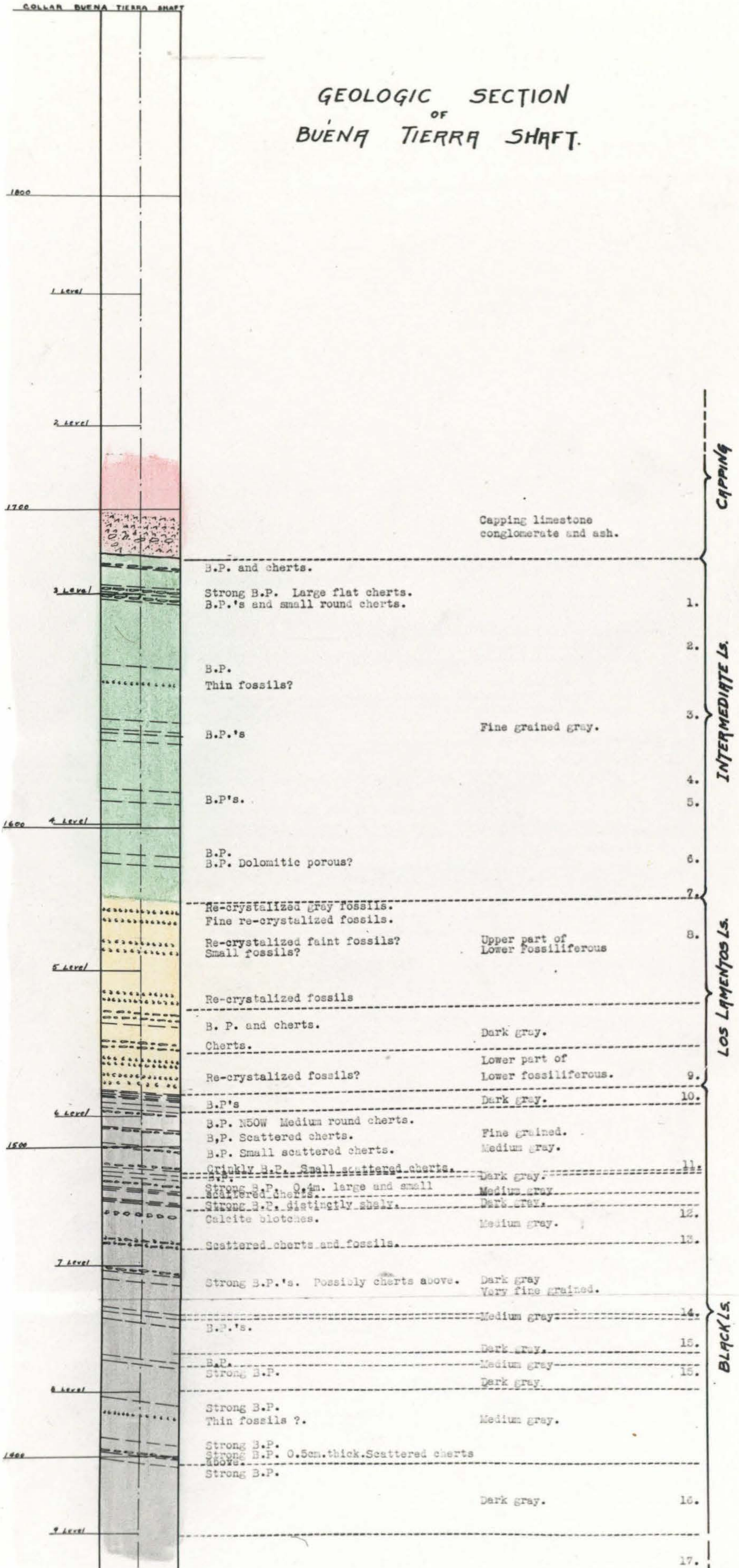


Figure 4.



GEOLOGIC SECTION OF BUENA TIERRA SHAFT.
COLLAR BUENA TIERRA SHAFT
1800
1 Level
2 Level
1700
3 Level
1600
4 Level
5 Level
6 Level
1500
7 Level
8 Level
1400
9 Level
Capping limestone conglomerate and ash.
CAPPING
B.P. and cherts.
Strong B.P. Large flat cherts.
B.P.'s and small round cherts.
1.
2.
B.P.
Thin fossils?
3.
B.P.'s
Fine grained gray.
4.
B.P's.
5.
B.P.
B.P. Dolomitic porous?
6.
7.
INTERMEDIATE Ls.
Re-crystalized gray fossils.
Fine re-crystalized fossils.
Re-crystalized faint fossils?
Small fossils?
Upper part of Lower Fossiliferous
8.
Re-crystalized fossils
B. P. and cherts.
Dark gray.
Cherts.
Lower part of Lower fossiliferous.
Re-crystalized fossils?
9.
LOS LAMENTOS Ls.
B.P's
Dark gray.
10.
B.P. N50W Medium round cherts.
B,P. Scattered cherts.
B.P. Small scattered cherts.
Fine grained.
Medium gray.
Crinkly B.P. Small scattered cherts.
B.P.
Dark gray.
11.
Strong B.P. 0.4m. large and small scattered cherts.
Medium gray
Strong B.P. distinctly shaly.
Dark gray.
Calcite blotches.
12.
Medium gray.
Scattered cherts and fossils.
13.
Strong B.P.'s. Possibly cherts above.
Dark gray
Very fine grained.
Medium gray
14.
B.P.'s.
Dark gray.
15.
B.P.
Strong B.P.
Medium gray
15.
Dark gray
Strong B.P.
Thin fossils ?.
Medium gray.
Strong B.P.
Strong B.P. 0.5cm.thick.Scattered cherts above.
Strong B.P.
Dark gray.
16.
17.
BLACK Ls.

LOS LAMENTOS LIMESTONE
(Lower Fossiliferous)

The Los Lamentos conformably overlies the Black limestone. It is a light gray, medium grained, rather thick bedded, highly fossiliferous limestone. A general spotted appearance occurs as a result of the coarsely crystalline calcite replacement filling of the invertebrate fossils. The most conspicuous fossils are corals, and loosely coiled pelecypod shells (Caprina) which usually give a circular to elliptical section.

The average thickness of the formation thruout the mineral zone is 75 meters ($\pm$ 250 feet). Underground the Los Lamentos Limestone has approximately the same color as the formations above and below, but is easily differentiated from them by the abundance of the fossils, the more crystalline texture, and thicker bedding.

There exists no marked chemical difference between Los Lamentos, Black, and Intermediate limestone. Locally large areas of manganese stained rocks (paint-rock) are encountered.

Productive manto horizons occur associated with marker beds U-7, 8, and 9 in the lower 75 feet of the formation. Ore bodies within a formation may connect or step from one horizon to another but outside the central chimney area it is rare that an ore body enters another formation. The Los Lamentos has in the past been one of the most productive manto formations in Mexico.

The upper and lower parts are very fossiliferous but the middle section contains rather scanty fossil material. The Los Lamentos district from which the formation derived its name shows the same zonal arrangement of the fossils. A transitional change marks the upper limit of the formation.

INTERMEDIATE LIMESTONE
(Fetid Beds)

A semi-argillaceous limestone conformably overlies the Los Lamentos. This is locally called the Intermediate limestone and the name is being used thruout northern Mexico for these beds.

It is rather thin-bedded and contains a number of irregular chert bands. The bedding planes are distinctly marked and many times contain a thin clay seam. Fossils are sparsely distributed thru several beds in the lower part of the formation.

An average thickness is about 225 meters (± 750 feet). In parts of the district the overlying Bufa and a part of the Intermediate limestones has been removed by erosion preceding the deposition of the capping.

The formation is commonly reported as unmineralized which is, however, erroneous. It is true that the long mantos occur in the overlying Bufa and the underlying Los Lamentos, but a small production has been made from mantos within the Intermediate limestone.

Nine marker-beds have been determined within this formation and of the Beds U-2 and U-3 have proved to be important loci for mineral deposition. A small tonnage of siliceous silver ore was found associated with marker-bed U-5.

The contact of the Intermediate with the younger Bufa formation is a sharp bedding plane associated with bands of cherts. The contact is designated as the U-0 marker.

The dark beds of this formation give a fetid-odor when struck with a hammer and beds in contact with each other often show a great difference in density.

BUFA LIMESTONE FORMATION

The youngest limestone in the district is the great cliff-forming Bufa formation. The lower portion only remains within the district and locally is completely absent.

The maximum observed thickness is about 200 meters (± 650 feet). The Bufa is locally called the Upper Fossil limestone, but as a regional term it may better be referred to as the Bufa limestone. It belongs to the Fredericksburg group of the Comanchean.

The limestone is physically comparable to the Los Lamentos limestone in that it is a massive, thick-bedded, medium dense, light colored, fossiliferous limestone. The calcite filled fossils are easily distinguished by their form from those of the Los Lamentos limestone.

The longest, most continuous mantos in the district occur in the Bufa formation. The most important ore-bearing horizons are listed as the U-30 to U-40, U-55 to U-70, U-100, U-120, and

U-140. The numbers indicate the distance in meters above the base of the formation, marker U-0.

INTRUSIVE ROCKS

The only intrusive rocks outcropping or encountered in the mines are the post-mineral dikes and sills. These may be divided into two classes as follows:

1. Acidic dikes; most widely distributed and probably earlier than the basic dikes.

2. Basic dikes and sills, probably end-stage emanations.

The dikes, especially the acidic porphyritic type, are widely distributed over the district. They are usually very thin and highly altered. All the dikes are later then the major mineralization and cut the limestone, ore bodies, and the capping. However, following the dike intrusion small movements occurred on the N 30 degrees E fractures and occasionally these breaks were healed with coarsely crystalline galena and calcite.

The dikes usually follow the Northeast fissures system, especially the N 55 degrees E fractures, and in exceptional cases are diverted from this class into one of the other two main systems for a short distance. The whole trend and attitude of the intrusives indicate a fissure filling.

The basic rocks are found near the larger chimneys. That is, the Mina Vieja Dike is near Mina Vieja Chimney; Potosi Dike is in the vicinity of the largest chimneys of the district; and the Inglaterra Dike is associated with the Inglaterra Chimney ore body. Known sills are rare, altho they do occur and recent diamond drilling has cut one which probably is associated with the

Potosi Dike.

Fresh samples of the acidic dikes could not be found. The specimens obtained show almost complete alteration. The best samples obtained show a genetic relationship between all the dikes of the group. In general appearance the dike is a light-colored, porphyritic fine-grained rock, outcropping usually with a very light red color. Under the microscope the specimens show extensive alteration, principally carbonatization and sericitation, but no deformation. They have a fine-grained texture with the larger grains seldom reaching a diameter of 2mm. The original texture of the rock as decided from petrographical studies was semi-crystalline, massive, slightly porphyritic. The secondary texture is one of pseudomorphs and aggregates. The ground mass is an aggregate of intensely altered acidic minerals from quartz to sericite, with a large amount of carbonate. Small zircon crystals are recognizable. The history of this group is comparatively simple. The acidic dikes are all genetically related and represent intrusives which have been extensively altered by escaping emanations following crystallization. The dikes have not been subjected to marked deformation since their injection, hence the complexity is a result of alteration and replacement. This group may be classified as a sericitized rhyolite porphyry.

The second class of dikes are decidedly more basic and in general have a more crystalline structure. Fairly fresh samples representing this group may be obtained from the Potosi Dike, or the Big Dike as it is commonly designated, and from drill cores of the Potosi Mining Co. This group has a dark green, finely crystalline appearance. Under the microscope the texture is medium grained with the size of the grains reaching a diameter of 3 mm. The original structure may be defined as a slightly porphyritic crystalline massive, with aggregates and psuedomorphs developed as a secondary texture as a result of alteration and end-product emanations.

The essential primary minerals are feldspars, including the medium acid plagioclase feldspars and some orthoclase. The fer-fomagnesiums have been almost wholly altered. Amygdaloical structure is occasionally encountered. The olivine has been completely altered to serpentine and cholorite. Occasionally an unaltered pyroxene mineral is encountered. A small amount of magnetite and quartz complete the list of primary essential minerals. The primary accessory minerals are usually apatite, with an occasional suggestion of pyrite. The chief alteration products are chlorite, epidote, serpentine, carbonate, and leucoxene. A large amount of introduced carbonate is present. Flow structure is developed in the Potosi dike. The general composition of the different rocks of this group vary from an olivine basalt to a diabase. The different dikes are undoubtedly from the same source which was probably a gabbro or quartz-diorite. The end-product emanations are chiefly responsible for the intense alteration.

There is a decided differenced of opinion concerning the age of the Inglaterra Dike, with the majority holding that this particular dike is pre-mineral. However, the microscopic analysis of this dike shows a genetic relationship to the Potosi dike a short distance to the north. The fact that this dike is mineralized within certain zones is the chief support of the pre-mineral view. Later in this paper it will be shown that this view is erroneous, and that the mineralization preceded the intrusion of the dike material.

SUMMARY DESCRIPTION OF THE CAPPING ROCKS

A thick series of volcanic flows, tuffs, tuffaceous-conglomerates, and conglomeratic-tuffs was deposited upon the eroded Comanchean limestone, filling the deep arroyos and gullies. The thickness of the capping series is unknown. It was probably very thick as over 500 meters (1650 feet) remain in the district.

Deposition was intermittent and during the intervals of quiescence erosion was very active. The intercalated series of conglomerates and tuffs were deposited very fast, and the periods of erosion relatively short in a probable arid climate.

The age of the capping has been the subject of much discussion. Many regard the age as later than the principal ore-deposition. However, it will be shown that the capping is probably older than the manto deposits.

Following deposition of the capping and later mineralization the limestone, ore bodies, and the capping were cut by a series of dikes.

Economically, the capping exercised some control of the depth of oxidation; geologically, the capping played an important role in controlling uniformity and continuity of the upper mantos.

The Cretaceous limestone was subjected to uplift and deep erosion before the beginning of volcanic activity. The surface was cut by gorges and a late youthful stage of topography was produced. It presented a much sharper relief than that of the present range.

BASAL CONGLOMERATE
(First Conglomerate)

The first conglomeratic formation is the oldest member of the capping series, and is very restricted in occurrence. It possibly had a wider distribution and thickness, and was largely eroded preceding volcanic activity. The more probable hypothesis is that it was originally restricted in occurrence. The contact of the limestone with the capping is extremely irregular, and apparently the position of the Basal conglomerate was confined to the arroyos and canyons.

The basal conglomerate is composed chiefly of limestone boulders and pebbles. They are well rounded and semi-polished. The boulders appear to be principally Bufa Limestone.

A typical exposure of the conglomerate is observed in the arroyo north of the town of Santo Domingo, about 200 meters (656 feet) south-east of the Velardeña Shaft. Here the formation reaches a thickness of 20 feet, the maximum observed thickness in the mineral district.

Several shafts, notably the Buena Tierra main shaft and the Potosi No. 3, have cut thin lenses of the Basal conglomerate. It is dark gray, very similar to the limestone, and a calcareous cement, subsequently silicified, forms the matrix.

LOWER TUFF

The Lower Tuff, or First Tuff, overlies the limestone except in the restricted areas where thin lenses of Basal Conglomerate separate the two. Within the mapped area, the tuff formation is characterized by a marked variance in thickness. This was caused by the uneven character of the surface upon which the tuff was deposited. Steep contacts occur where it has filled old arroyos. In a gulch north of Santo Domingo, the contact between the Bufa and the tuff is locally vertical. Here the angles of the tuff layers reach over 30 degrees dip away from the cliffs.

The First Tuff, at a glance, appears to be a series of flows. It is composed principally of angular fragments of rhyolite with a minor amount of limestone fragments in a matrix of volcanic ash. A crude bedding exists. Silicification has altered and cemented the original tuff and at the same time, has given the formation a greater similarity to a rhyolite flow. The rock may be classified as an altered granular to fragmental tuff with a rhyolitic matrix. Physically the formation has the appearance of being of rapid accumulation, and is homogenous in texture from the bottom to the top of the formation.

At the Potosi No. 2 shaft, the tuff has a thickness of 200 meters (± 650 feet) and increases to 225 meters at the Potosi No. 1 shaft. The deposit thins to the north and at the Purisma shaft is only 10 meters (32½ feet) thick. Similar discrepancies in thickness are noted in other parts of the mapped area.

The Pueblo of Santo Domingo is built on the Lower Tuff, altho the 'Patio' at the Potosi is an accumulation of limestone dump material. The Lower Tuff undoubtedly covered the entire range as well as the Real de la Santa Eulalia.

In general, the Lower Tuff maintains a N-S to N 30 degrees W strike and dips to the SW with angles varying from 5 to 30 degrees. It apparently reaches a much greater thickness in the undifferentiated area to the east. The ridges, or cordons, visible from the area worked, contain an even greater thickness than the mineral district. The road from Santo Domingo to the town of Santa Eulalia passes thru this member of the capping.

Following the outpouring of the basal tuffaceous material, a short period of quiescence occurred and during this time the Tuff was subjected to silicification and to erosion. Activity was then renewed with the outpouring of the overlying flow.

RHYOLITE FLOW

Renewed volcanic activity followed the period of erosion which closed the lower Tuff accumulation. The pouring out of a rather viscous rhyolite over the entire Santa Eulalia range resulted from renewed volcanic activity.

The flow is, in general, light-buff colored, massive, fine grained, quite indurated, and has a marked flow structure. It is composed of quartz and alkali feldspathic phenocrysts in a dense matrix. Occasionally, a splinter-shaped fragment of volcanic glass, or altered feldspar laths are found. The principal alteration product is sericite. Subordinate amounts of secondary quartz also appear. The ferromagnesium minerals are principally titanite and pyrite. These are found only in a very fresh piece of rock. The orientation of the phenocrysts and bands of color mark a very definite flow structure.

The color of fresh rock varies from dark-gray to light-buff while the outcrops are usually iron stained. In fact, within the mineral zone, the whole capping series is characterized by a reddish-brown color.

The gulleys which had been cut into the Lower Tuff were filled by the flow and the entire surface covered. The maximum observed thickness within the differentiated area is 100 meters (± 325 feet). In several places, the formation had been completely removed by erosion before the deposition of the overlying tuff.

Characteristic sections may be observed about 10 meters above Potosi No. 1 shaft, Potosi No. 4 shaft, Buena Tierra North Shaft, and about 10 meters above the Velardena and Dolores shafts. The railroad cut from Santo Domingo to Galdeano exposes a typical section between Potosi No. 1 and the Peru shaft. The flow appears to be thicker near Galdeano than within the differentiated area. A large discordance is observed in the strike and dip of the flow in different parts of the district.

SECOND TUFF

Upon the somewhat eroded surface of the Rhyolite Flow, a second tuff deposition occurred. Spurr has designated this as the Second Tuff in a private report on the area.

In a fresh state, the tuff is brown to buff colored, and Its outcrops are usually iron stained, imparting a brownish-red color to the formation.

The Second Tuff is frequently absent and attains a maximum thickness of only 40 meters within the mapped area. It is distinctive in composition from the First Tuff which was composed principally of rhyolite fragments and limestone in a rhyolite matrix. The Second Tuff is composed of andesite and rhyolite fragments in a matrix of andesitic material. Ordinarily the fragments are small, but in some places the tuff becomes a breccia. In addition to the coarse grained andesite-rhyolite particles, the matrix shows phenocrysts of feldspars and quartz.

Alteration minerals are abundant. Chlorite, zoisite, calcite, and epidote(?) are recognizable.

A typical exposure of the Second Tuff occurs a few meters north or northwest of Potosi No. 2 shaft where it is 40 meters (± 130 feet) thick, the largest measured section in the area. Fresh tuff is also found in back of the church of Santo Domingo and a fragmental facies of the formation occurs in a gulch near the Reina de Plata Shaft.

SECOND CONGLOMERATE

The Second Conglomerate was deposited rather evenly over the Santa Eulalia district. The remnants that remain have a thickness of about 50 meters ($\pm$ 164 feet).

The formation consists of well rounded limestone boulders and pebbles with a large amount of rounded tuff fragments. Minor amounts of rhyolitic rock occur and these are evidently derived from two different rhyolitic facies. Part of the rhyolitic material was undoubtedly derived from erosion of the Rhyolite Flow. Most of the rhyolitic material found in the Second Conglomerate is very glassy in texture, patches of obsidian are common, and phenocrysts of orthoclase are more abundant than the lath-shaped phenocrysts in the Rhyolite Flow. The country surrounding the Real de Santa Eulalia, which embraces the mineral district, was apparently much higher and evidently the aphanitic material was derived from the more elevated land.

The conglomerate is well cemented by tuffaceous material and shows some secondary silicification. The formation was rapidly accumulated during a period of quiescence of the volcanic outpourings. The boulders composing the greater part of the conglomerate are Bufa limestone. Coarse calcite replacements of Bufa fossils occur in the boulders.

The tuffaceous material grades from well rounded boulders in the lower part of the formation to fragmental tuff blocks in the upper section. It is partly andesitic, similar to the Second Tuff and partly rhyolitic boulders, similar to the First

Tuff. The material was probably derived from the elevated surrounding country.

The upper contact of the formation is arbitrarily chosen, as the succeeding formation is a tuffaceous conglomerate.

When fresh, the Second Conglomerate is a light gray. The greater part of the outcrop is stained by iron oxides.

Typical exposures of the Second Conglomerate cap the hill above the Buena Tierra North Shaft, and a wide belt is exposed just north of the Velardena Shaft.

THIRD TUFF

The Third Tuff is thin, and lies on the uneven surface of the Second Conglomerate. It is a variation of the underlying conglomerate in which the tuffaceous material is in excess of the limestone boulders. The tuffaceous material is principally andesitic, similar to the Second Tuff. The matrix is also andesitic.

The formation might very well be included in the Second Conglomerate formation. Mr. Spurr, however, separated the two formations and mapped them as separate units within the differentiated area, and they are, therefore, presented as individual formations in this brief description of the capping rocks. It forms the capping rock of several of the peaks. A fine exposure occurs a few meters west of the Reina de Plata Shaft.

The formation is gray to light buff in color, and, therefore marks a very prominent band in the series.

THIRD CONGLOMERATE

The Third Conglomerate is similar to the Second Conglomerate, but differs in having a decided predominance of tuff over the limestone boulders. The matrix and cement are andesitic. Similar to the other conglomerates, this formation is really a tuffaceous-conglomerate bordering a conglomeratic-tuff. The remnants are restricted in areal distribution and reach a maximum thickness of 50 meters ($\pm$ 165 feet). The best exposure of the Third Conglomerate is in Potosi No. 3 shaft. Northwest of the Velardeña Shaft is a remnant which forms the capping of a low hill and shows recent displacement. Aside from this remnant, the formation outcrops only in the southern part of the differentiated area. Another pause in the volcanic outpouring is recorded in this formation as it was subjected to erosion, following or during its deposition.

It is dark gray to brownish-buff in color.

FOURTH TUFF

The highest stratigraphic member of the district is the Fourth Tuff which was deposited upon the eroded surface of the Third Conglomerate. The thickness of this member is problematical. In composition, it is very similar to the Third Tuff. The ratio of the andesitic material to the rhyolitic is somewhat higher. Fresh rock is scarce. The material has been almost completely altered.

The thickest sections of the Fourth Tuff occur west of Santo Domingo on the slope of the hill. The largest remnant is above 100 meters south of Potosi No. 3 shaft on the same slope.

FISSURE SYSTEMS

At various times major faulting and fissuring accompanied by minor faulting has occurred. Some fracturing accompanied or closely followed the gentle folding. The folding probably occurred after deposition of the volcanic mantle but earlier than cementation of the mantle. Fissuring was initiated earlier than ore deposition, but some fissures show post-mineral movement along pre-mineral breaks. The partially silicified capping was broken by the post-mineral disturbance.

Previous reports on the district only record one group of pre-mineral fissures. The present study defines three systems of pre-mineral age. Only those fissures in the mining district proper (Pl. 2) will be discussed in detail.

The present classification of the fissures has been made possible by investigation of the lower levels of the Potosi mine. Here pre-mineral fissures occur with different trends and age and cxidation has not obliterated relationships. The similarity of the limestone beds of different horizons tend to obscure the true conditions but it is found that minor displacements are not uncommon. Displacements of over 10 feet, however, are rare.

The prominence of fracturing varies with the physical character of the limestone. Some beds are brittle and break readily, other argillaceous sections are compressed so that fracturing is not pronounced. A fissure zone may then, in its vertical range, be pronounced in some sections and almost unnoticeable in other horizons. Fracturing is most pronounced near the crest of folds. The sections most susceptible to breaking are the most favorable channels for ore-bearing solutions.

Fissures in the district are for convenience referred to in the singular, but actually designate zones instead of a single breaks.

Table No. 5 illustrates the fissures classified according to trend and the most pronounced zones associated with the ore bodies indicated. Fissures grouped according to system and progressive age are shown in Table No. 6.

GROUP 1 FRACTURE SYSTEM

The first group is referred to as the East-West System and has a general trend from E-W to N 65 degrees W. It is the earliest recognizable system in the district.

1. That is, the fracturing may have preceded the deposition of the capping; or
2. post-capping but preceding cementation of the capping rocks; or
3. post-capping, post-cementation with the action so gentle that the capping was unbroken.

Later movement on fractures of this system is decidedly post-mineral and has fractured the capping.

The fracturing was most pronounced in the southern part of the district, especially near the minor axis of the anticline. In the Potosi mine the N 65 degrees W sub-division represents tensional cracks parallel to and in the vicinity of the minor axis

TABLE NO. 5

CLASSIFICATION OF FISSURES

GROUP	CLASS	TREND	REMARKS	EXAMPLES
1.	E-W	E-W to N65 W	Pre-Mineral with Post-mineral action	Gypsum, L.S. Fissure, 'N' fissure, Peru, 'J' fissure
2.	N-S	N30 W N10 W N - S N10 E	Pre-Mineral	Purisma, Los Angeles, West Velardena-M, 604-Penoles Rosario, Chorro, Chihuahua, Hematite, Tunnel, Potosi, J North, A fissure zone, Dennis Zone, and 'E'. 'E' fissure example of N30 W.
3.	North-east South-west	N70 E N55 E N30 E	Pre-Mineral Post-Mineral action	R-30, F-30, San Lazaro, Dike fissure, Donald fissure zone, Guadalupe, Inglaterra N.E. No. 2 Velardena Fault.

of the fold. Dips are generally vertical, altho the 'N' fissure of Potosi has a pronounced dip to the south. The Gypsum, L.S., 'N', Peru, and 'J' fissure zones belong to this group. This system did not exert a pronounced control of the paths of mantos, but attains importance in connection with the location of chimneys and width of mantos. Where they intersect the N-S system, in favorable horizons, a noticeable enlarging of the cross-section occurs. Chimneys often occur at a zone of inter-

TABLE NO. 6

Age	Group	System	Trend	
PRE-MINERAL	1.	E-W	E-W to N 65 W	Oldest known fissures. The N 65 degrees W fissures are tensional cracks parallel to the axis of the anticline. Not a pronounced group as a mineral channel; however, important as the intersection of this group with the N-S class (group 2) within the numerous favorable horizons form the loci of spreading manto deposits, and intersecting zones, channels for the chimneys. This group in some places (i.e. 'N' fissure and Dennis Fissure zone) shows pre-mineral faulting by the N-S class.
	2.	N-S	N 30 W N 10 W N - S N 10 E	Younger than the E-W class. The four main trends of this group contemporaneous in formation. The N 30 degrees W a variation of the N 10 degrees W and the N 10 degrees E variations of the N-S. This group is the strongest in the district, and most persistent. This system governs the trend of the Bustillos-Galdeano and the Purisma-Mina Vieja-Velardena manto. The intersection of this group with either one or both the systems of cross-fractures form mantos within the favorable horizons, and chimneys at zones of intersection, the latter especially in the southern part of the district.
	3.	North-east South-west	N 70 E N 55 E N 30 E	Later than group 1 (E-W) and probably contemporaneous with the formation of group 2. The intersection of this group with the 2 preceding groups form the loci of the most important chimneys of the district.
POST-MINERAL	3a.	North-east South-west	N 70 E N 55 E N 30 E	Renewed activity along the Pre-mineral N-E group of fissures. The most important faulting in the district follow this system and may be defined as post-mineral movement along a pre-existing plane of weakness. Post-mineral movement which fissured the capping. The dikes follow the fissures of this group, usually confined to the N 55 degrees E class. Dry-caves follow this group.
	1a.	E-W	E - W N 65 W	Post-mineral action along pre-existing zones of weakness. Some minor faulting, fissuring of capping and the post-mineral dikes. Sometimes sealed with a late mineralization of uneconomic importance. Dry-caves not well developed as in group 3a.

section of this system with the N-S group.

The Dennis Fissure zone, of the N-S system, shows pre-mineral displacement of the 'N' fissure. Small pre-mineral displacements occurred on the 'J', 'N', and Gypsum fissures. Step faulting occurs in the 'J' fissure zone. The faulting, however, was of a minor character and accentuated by post-mineral activity along the same breaks.

The fissures of this system have exerted a greater control than the other groups on the location of ore bodies in depth.

GROUP 2 FRACTURE SYSTEM

The North-South system, Group 2, includes fissures that have a general trend of N 30 degrees W, N 10 degrees W, N-S, and N 10 degrees E. The dips seldom vary from the vertical. It forms the most persistent and important group of pre-mineral age in the district. Formerly it was considered the only pre-mineral system in the district. Supporters of this view either overlook the noticeable spreading of the deposits at the intersection of the group with the E-W and Northeast systems, and displacement; or they lack the information obtained from the study of the primary deposits of the Potosi mine. In most instances they have concluded that fissures perform a minor role in the location of the ore bodies, and in the determination of their general trend.

The general strike of the group is parallel to the major axis of the structure and they attain their greatest prominence on the crests of the two low angle folds paralleling the axis. The two gentle folds are the sites of the East and West mantos. In this group, it is remarkable how tight the fractures appear in the barren beds; that is beds which separate favorable horizons.

The absence in the 'capping' of fissures of this group does not necessarily imply pre-capping age, for the fracturing was tensional and only prominent in brittle strata. The capping was probably present at the time of fracturing and probably uncemented. Compression from the west-southwest apparently accompanied formation and is reflected in the slight curvature maintained by both the long East and West mantos.

The most prominent fissures of the group are the Purisma, Los Angeles, West Velardena-'M', 604-Penoles, Rosario, Chorro, Chihuahua, Hematite, Tunnel, Potosi, 'J' North, 'A', Dennis, and the 'E' fissure zone. The 'E' is a typical example of the N 30 degrees W fissure. The entire system was formed contemporaneously, altho occasionally later movement tends to complicate the interpretation.

GROUP 3 FRACTURE SYSTEM

The third group of fractures, known as the Northeast system, has a general N 30 degrees E to N 70 degrees E trend. It is composed of three sets of fissures. The first set has a general trend of N 30 degrees E and are almost vertical. The 'R' 30 and the 'F' 30 are typical examples of this sub-division.

The second sub-division has a general strike of N 55 degrees E with the San Lazaro, Donald, Guadalupe, N.E. No. 2, and the Potosi Dike fissures are typical examples. The N 70 degrees E fissures form the third sub-division and this trend is represented by the Inglaterra dike and the Velardena Fault trend.

Similar to Group 1, this system has in the past been considered as post-mineral in age. The evidence, however, shows pre-mineral formation with post-mineral activity.

The fracturing is later than Group 1 and possibly is contemporaneous with the formation of Group 2 Fracture System. The most important chimneys occur in zones of intersection of this group with the N-S or both the N-S and E-W groups.

During the period of mineralization the N-S group was the most continuous and open. The Northeast fractures were second in importance and, in several instances, the mineral-bearing solutions used this system to step to another N-S zone of fractures. The least important group was the E-W, altho in Potosi ground several of these fractures have been channels for the ore-bearing solutions stepping to the east and south-east.

GROUP 3a FRACTURE SYSTEM

Group 3a represents the 4th period of fracturing and is a renewed activity along the pre-mineral Northeast system, Group 3. The most important faulting within the mineralized zone is the post-mineral movement along the earlier established trend. The post-mineral movement also disturbed the capping.

Nearly all the dikes followed the post-mineral faults and reopened fissures. The dikes were usually confined to N 55 degrees E fractures. The Donald and Velardena Faults are two notable examples of post-mineral movement. The Potosi and Inglaterra Dikes represent fractures which were opened and later became the sites of intrusion. Faulting was not of great displacement. A ten meter throw is rare within the main mineralized zone.

Reopening of the pre-mineral fractures was more important than the faulting for the open fissures furnished the channels for the oxidizing solutions and became the site of barren-caves. A small amount of transported zinc was also deposited along fissures of this system.

More recent fracturing seems to follow the N 30 degrees E group of the 3a system, ~~and~~ The fissures were occasionally later sealed with coarsely crystalline calcite and galena.

The later displacement was along established planes of weakness and apparently after the intrusion of the dikes, so the introduction of a distinct system does not appear necessary.

A fissure cutting the Potosi Dike near No. 2 shaft shows that it is distinctly younger than the dike.

GROUP 1a FRACTURE SYSTEM

Post-mineral activity along the E-W system (Group 1) necessitates establishment of this group. Minor faulting accompanied the renewed fracturing. The capping was fractured and the breaks usually sealed by calcite and galena.

Gypsum fissure caves are exceptional cases of barren cave association in this group as well as in the 3a system.

It is noticed that there is a remarkable lack of brecciation accompanying displacement. Usually the movement has been distributed thru a zone of knife-like fissures instead of along one plane.

Post-mineral step faulting is noted along the 'J' fissure zone causing the mantos to appear to step from one bed to another. Movement is also found on the 'N' and Gypsum fissures.

ORE DEPOSITS

DEFINITIONS

<u>Chimney</u>

The term chimney, as used in manto districts of Mexico, refers to ore bodies that traverse the bedding of the enclosing rocks. When the formations are horizontal the chimneys are vertical, providing the fracturing is also vertical. The variation from the vertical position depends largely upon the attitude and width of intersecting fissure zones. Ore-bearing solutions ascended in the zone of intersection and followed a course of least resistance. Thus an irregular channel was attained during the start of mineralization and continued metasomatism finally produced an irregular pipe-like body traversing the bedding.

Deformation, both pre-mineral and post-mineral, produces chimneys ranging from the vertical to the horizontal, or intermediate positions. Where deformation has been practically absent, as in the Santa Eulalia District, the chimneys may be said to be universally vertical.

The Ojuela Mines near Mapimi, Durango, present the other extreme, a vigorously deformed area, and chimneys are found ranging from vertical to horizontal.

The transverse cross-sections of chimneys vary from an irregular circular to a long, elliptical shape. The longitudinal section varies directly with the size of the ore body; the larger the chimney, the more regular the outline; and the smaller the cross-section, the more irregular the longitudinal section. The nature of the different beds traversed is partly responsible for irregularities.

<u>Manto</u>

Manto: (del Latin Mantum) Min Capa de Mineral poco espesa y casi horizontal (Enciclopedia Sopena).
Manto: Capa (Min.) Veta horizontal (Nuevo Diccionario Enciclopedico "Miguel de Toro y Gomez").

The term is a Spanish term for horizontal veins or ore bodies that follow the bedding of the enclosing rocks. The term '<u>manta</u>' which often appears in literature concerning the Mexican deposits is erroneous and should be discarded. In Mexico, manto has come to have a more restricted meaning in connection with ore bodies and is used to designate long, narrow ore bodies following the bedding. A manto differs essentially from a flat or blanket deposit in the greater ratio of its length to its width. In strata favorable to ore deposition, the cross section of a manto shows that its habit is to ascend from its chimney source to successively higher stratigraphic strata.

Mantos, in general, show a gradual decrease in cross-sectional area away from their chimney source. Mantos range from horizontal to vertical, depending upon the attitude of the formations in which the ore bodies occur. In a region little deformed, Santa Eulalia, for example, the mantos are almost horizontal; while in a vigorously deformed region, such as Ojuela, they range from the horizontal to the vertical and the connecting chimneys also show a corresponding range in attitude.

Naturally the combination of the two forms, mantos and chimneys produces ore bodies in all degrees of attitude. Often mantos jump for a short distance from one favorable zone to another.

Hilo — Hilo is the Spanish word for thread. When applied to ore deposits in Spanish-American countries it refers to thin seams or veinlets not thick enough to be called vetas or veins. In connection with manto deposits the term has been applied to the wings, or thin blankets which extend laterally from the manto. In cross-section, the typical primary manto ore body is shown in figure No. 6.

Removal of limestone beneath a manto section by acid solutions generated during oxidation lowers the oxidized ore relative to the site of the primary ore body. This leaves the partly oxidized hilos stranded above a manto (Figure No. 7). It is not uncommon to have more than one set of hilos associated with an ore body.

Ore-bearing cave-locally called shrinkage cave. An "ore-bearing cave" is the open space existing above an oxidized manto. It is formed by the lowering of the oxidized ore during oxidation thru removal of limestone beneath the manto section by acid solutions, and by collapse which continues until the roof becomes a stable arch. The site of the primary ore is marked by the hilos which extend outward from the walls of an ore-bearing cave. Ore-caves have a greater breadth than height.

Barren cave -commonly called dry-cave, is a product of oxidation. It marks a circulation channel during oxidation. The form varies from a cavernous fissure to a large cave system. The caves have greater height than width. They are usually barren, altho occasionally contain some secondary iron and zinc minerals.

To facilitate description, the ore bodies of Santa Eulalia will be divided into six groups, as follows:

1. East Mantos-(Galdeano-Bustillos-Central mantos).
2. West Mantos-(Mina Vieja-Purisma chimney and mantos, Velardena mantos, Jean Cave manto, Caterina and Lower manto, Upper Ojuela, 'E' ore body, etc.).
3. Potosi Chimney area-(all the major chimneys and the associated connecting mantos).
4. Southern Extension-(Inglaterra area).
5. Parcionera Manto, including Santa Rita ore body.
6. Isolated ore bodies-(mantos, chimneys, and irregular capping ore bodies).

1. EAST MANTOS
(Galdeano-Bustillos-Central Manto)

A long narrow ribbon of ore known as the East Mantos extends north from the East-West trending 'G' ore body (see Plate No. 3). This manto extends unbroken a distance of 7400 feet north from the 'G' ore body. Several segments now separated by erosion, but which were formerly parts of the same manto extend 2600 + feet farther north giving a N-S length of over 10,000 feet. Altho the general trend is to the north, the manto is very erratic locally, which increases the length of the ore body to a total of 12,500 feet.

From the 'G' ore body, the East Mantos extend north in a thin section of Bufa limestone. The average thickness of the remaining Bufa is about 75 meters or 250 feet.

The first 600 feet of the East Mantos is known as the Galdeano manto. The ore body rises from a short distance below the top of the Intermediate limestone to almost 200 feet above the base of the Bufa. Its ascent was made by a series of short chimneys and mantos in a north-south zone of fissuring. The chimneys occur where the system is traversed by the northeast group of fissures. One fissure traversing the center section of the Galdeano stope is the site of a barren-cave which occurs below in the Los Lamentos limestone. The cave is noteworthy as it contains a large body of water, altho the rocks of the district, in general, are dry.

The Galdeano was one of the first ore bodies to be worked by the Spaniards. The ore averaged about 3 kilos of Ag and 4% of Pb per ton.

The succeeding 300 feet north is known as the Gypsum Pillar section. The southern part of the Gypsum Pillar stope is a typical manto while in the north the ore body divides, part of the deposit assuming a chimney form, the remainder a manto extending north. The chimney outcrops 250 feet above the manto, altho the greater portion of the ore body is diverted as a manto before reaching the surface. This upper manto continues north unbroken for 6500 feet. The Gypsum Pillar section contains rather low grade ore with a large amount of gypsum and shows the effect of considerable leaching. The ore occurs below a gypsum cover, and according to the meager statistics and the material found during the reworking of the stope, averages only 300 grams Ag and 4% Pb per ton.

A lower manto, continues north beyond the chimney described above, is a direct extension of the Gypsum Pillar manto in the same horizon and has a length of 650 feet. This is the famous Bustillos Manto. It has a north-south trend and the section follows the same fracture zone which governs the Galdeano manto. The north end has a large cross-section when it meets a north-east fissure zone with a long system of associated barren-caves. There has been some post-mineral movement along this zone and a supposed extension of the strong Bustillos manto has not been found. The average cross-section of the manto is 1500 square feet. The entire Galdeano-Bustillos manto averages 3 kilos of Ag., and 4% Pb per ton with occasional pockets of high grade silver ore.

The manto diverted north from the Gypsum Pillar chimney follows a N 30 degrees E fissure zone a distance of 650 feet. This fissure zone at the intersection with the N-S group which governs the Galdeano-Bustillos ore bodies is the site of the Gypsum-Pillar chimney. The ore body extending to the northeast is known as the San Juan manto. It is one of the first worked bodies in the district. Numerous shoots of ore were stoped to the surface at places and the thin intervening cover has in general caved ~~in places~~ making the stopes partially inaccessible. The San Juan manto ends to the north as a shoot or chimney where the ore body extends downward over 100 feet to another favorable manto section. The deposit again assumes a manto form and spreads to the north governed by a north-south fissure zone. The total length of this section is 800 feet. It crosses without displacement, the N 30 degrees E fissure zone, which forms the abutment for the Bustillos manto at a lower horizon. The pipe at the north end of the section is known as the El Nublado chimney.

The Nublado chimney at its lower end connects with a manto which continues to the north. A barren or leached zone occurs in the manto 250 feet north of the El Nublado chimney. This is known as the Dry-Cave section and is 150 feet in length.

The northern extension from the Dry-cave area, 7000 feet long, is composed of the Cristo, Juarez, Sol Alto, Carter Beggs, and Plaza Norte sections. These mantos lie within a few feet or in contact with the capping. It is one of the best examples in the district showing an ore body following the relief of the old topography. There has been no consensus of opinion concerning the age of the manto. The ore body enters the capping at several places, a point which is frequently overlooked or disregarded. This is not in accord with the theory of pre-capping mineralization.

The roof of the shrinkage or ore-bearing caves, where the manto is in contact with the capping, varies from an altered tuff to a conglomerate. Some of the boulders in the conglomerate are several meters in diameter. Alteration of the capping in contact with the ore body has been carried to the end-stage, leaving a soft, iron-stained, kaolinized material.

The primary segregations or masses in the capping have usually escaped oxidation, altho the ore in the limestone is completely oxidized. Both the sulphide and oxidized ore show a high silver, low lead ratio and will be discussed later. The oxidized ore averages 3-5 kilos silver and 4-5% lead.

The general trend of the section is N 10 degrees W. The manto occasionally steps to the west in fissure zones of the N-S and E-W systems. This gives a slight curve or crescent shape to the East Mantos which is analogous with the West Mantos, to be discussed in the succeeding group. In both groups, the trend is nearly coincident with the strike of the major axis of the anticline and particularly with the axis of the slight warps which mark the structure of both the East and West Mantos. The relation of the fracture systems to the trend of the mantos is shown on the structural map of the district. (Plate No. 2).

At two points in the Central section ~~are~~ short chimneys occur. In both, the ore body extends down into the Intermediate limestone. Mining maps are vague concerning these two caved and filled stopes, so the termination of them is unknown. Whether or not mantos extend north from the lower section of the chimneys is problematical.

Several irregular bodies that are undoubtedly segments of the primary deposit lie north of the continuous section of the West Mantos. The most northerly of these, the Buen Retiro, is separated by erosion from the Las Animas manto. The Las Animas is separated by erosion from the segment to the south known as the Florencia ore body. However, the Florencia will probably be found to connect with the northern end of the Galdeano-Bustillos-

Central manto. A high silver and low lead type of ore, similar to the Galdeano-Bustillos Central manto, is general, except in the case of the Buen Retiro. The Buen Retiro is one of the old mines and no records are available as to the character of the ore originally mined. The remaining ore, however, is lower in grade than the average East Manto ore.

2. WEST MANTOS

The group of ore bodies known as the West Mantos is in marked contrast to the East Mantos described above. The total length of the West Mantos is about 7000 feet; much shorter than the East Manto. The mineralized area, however, has produced many times the tonnage of the East Manto.

The ore bodies in the Los Lamentos limestone are confined to one section, while several mineralized zones occur in the Bufa.

A study of the plan and section (Plates No. 3 and 4) shows the magnitude of the mineralized area and the complexity of the mantos in this group.

A complex group of mantos and chimneys compose the West Mantos. The ore bodies of the southern part are successively connected, from the lowest to the highest, to the Chorro Chimney at elevations corresponding to favorable manto horizons; while those of the northern part of the unit have apparently a genetic relation with the Mina Vieja chimney.

The ore bodies from the Chorro chimney gradually ascend toward the south and are very definitely controlled by structure.

Three sets of ore bodies extend north from the enormous Chorro or Santo Domingo chimney. They are:

1. The Upper and Lower mantos of the 'N' ore body and their extensions into the Catarina, 200 -, San Juan, San Pablo ore bodies, and the extensions north thru Velardena ground

2. The Upper and Lower Ojuela and their extensions north

3. The radiating extensions of the Eastern ore body

The northern part of the West Mantos was worked in some of the oldest mines of the district, namely, the San Matias, Death cave, Burro Road, El Toro, Labor Grande, Restaurant, Upper and Lower Concepcion, El Sueno, Los Angeles, and Santa Barbara stopes; also the large chimney extending down thru the Intermediate formation, known as the Mina Vieja or Purisma chimney. The upper mantos were apparently mineralized from the Mina Vieja chimney. The related mantos ascend gently away from the chimney, both to the north and to the south. The favorable horizons were chiefly fossiliferous beds near the base of the Bufa limestone.

Incomplete records indicate that the low grade Ag ore consisted of oxidized lead minerals in a siliceous gangue and low silver content, quite different from the high silver-low lead ore of the East Manto. Several mantos have developed a great width for the district, and attempts to extract the ore to its limits have resulted, in several instances, in disasterous collapses of the cave roofs. The most tragic occurred in Death Cave where the roof collapsed between two diverging fissure zones.

The ore bodies of the northern end, in general, have a N 10 degrees W strike. This zone where intersected by the Northeast system apparently forms the loci for the ascending ore bearing solutions responsible for the associated mantos and the Purisma or Mina Vieja chimney.

A peculiar feature of the chimney, paralleled in other parts of the district, is the occurrence of a shell of silver impregnated limestone--locally known as pay-lime, which can be profitably mined for its silver content. Physically, the limits of this mantle cannot be determined, and, therefore, extraction must be accompanied by a very careful sampling.

The chimney is very irregular in the Intermediate limestone. It is greatly restricted near the base, but expands upon entering the Los Lamentos formation. A large manto extends south from the bottom of the chimney. This ore of this lower manto was erratic in metallic content.

West of the Mina Vieja chimney, in the Los Lamentos formation, is the long, narrow P 1053 ore body. ~~and~~ Any connection this may have with the main ore body is not apparent. The P 1053 stope follows a N 10 degrees W fissure zone and is veinlike in character. The ore body averages 12 feet in width, but a narrow manto occurs in the south. It has been mined 75 feet vertically. It is a recent discovery and may prove to be the feeder to the Mina Vieja chimney.

From the south end of the West Manto a complex series of ore bodies extend north from the Chorro Chimney and forms the south end of the West Manto unit. One strong horizon exists in the Los Lamentos and three in the Bufa limestone. The mantos in the Bufa pass from one favorable bed to another. This change occurs at pronounced fracture zones.

The oxidized ores of the mantos in the Bufa were derived from a primary body with a high lead-high silver,-low zinc sulphide content. The oxidized ore consists of beds of anglesite and cerussite, interbedded with a low grade ferruginous ore. The sequence of the beds is often repeated in an ore body.

The productiveness of the Los Lamentos in the northern part of the West Manto has already been mentioned in connection with the mantos extending south from the Mina Vieja chimney. The same formation is the site of an important ore body, the Jean Cave, extending north from the Chorro chimney. This manto has been studied by geologists for the past 25 years and many conflicting ideas have been advanced concerning it. Prescott[1] in his recent paper includes a plan of the Jean Cave ore body and describes the course as being unique and conclusive to one of his principles, namely, lack of fissure control. (Fig. No. 8).

The ore body from the Chorro chimney to the top of the Black limestone is a group of short chimneys and mantos. The strike of this section is controlled by the Northeast and N-S fracture systems.

The Jean Cave is confined to the central part of the Los Lamentos limestone, just below the upper fossil zone, in the

1. Prescott, Basil--i.d. pp. 8

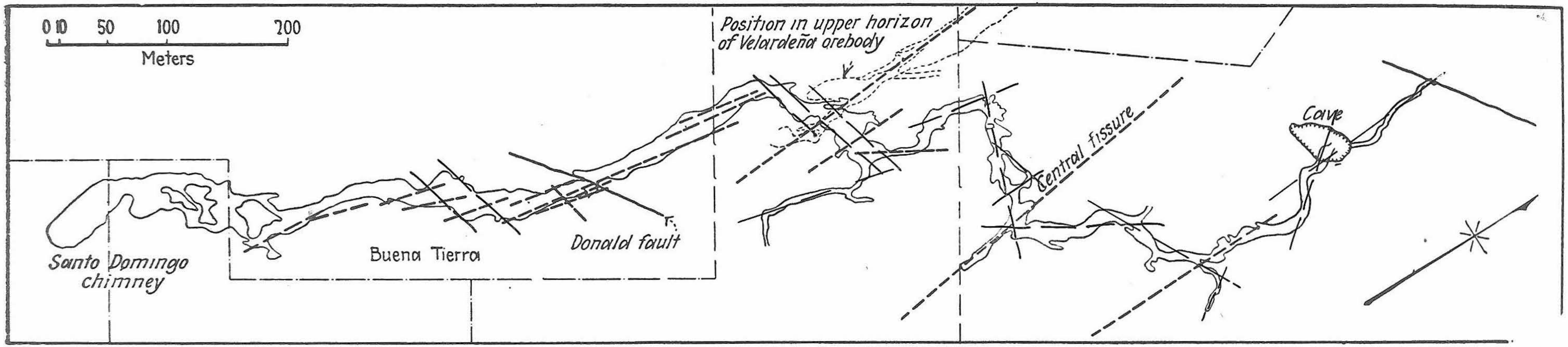


Figure 8. Jean Cave Ore body showing the relation of the deposit to the pre-mineral fissures. (Modified after Prescott.)

Buena Tierra claim. The strike of this section is governed by N-S fractures. The manto changes its strike at a strong northeast fracture zone near the southern end of the Velardena claim. The manto was governed by the fractures and did not "wander erratically across the country," but ~~by~~ follow different zones, first one group, then another, in the Velardena claim. In the Central, the manto again has a N-S strike. Prescott's assumption that the N-S system was the only pre-mineral fissures, probably led him to conclude that fissure control was not an important factor.

A compression from the southwest during deformation produced a slight warping or doming of the Los Lamentos formation in this area which allowed the ore-bearing solutions to reach the crest of the gentle fold. Likewise, the manto that extends south from the Mina Vieja chimney steps eastward and ascends toward the south on the same subordinate structural feature.

Near the south side of the Buena Tierra property, the Jean Cave ore bodies have the form of mantos. The ore body, a short distance south of and for over 500 feet north of the Donald Fault, had a greater vertical than horizontal extent. In the Velardena claim the Jean Cave ore body is essentially vertical and vein-like with vertically banded high temperature minerals. The strong Penoles-604, or Central fissure, crosses the Jean Cave ore body in the Central claim. The fissure was mined vertically from 200 feet below and thru the total thickness of the Los Lamentos formation in the vicinity of the manto. The ore was a vertically banded high lead-low silver type ore. The fissure was apparently mineralized contemporaneously with the Jean Cave manto, altho the lead-silver ratio is decidedly different. The Jean Cave section averages 350 g. silver and 12% lead while the 604-Penoles fissure averages only 150g silver and 22% lead. A study along the length of this fissure zone and the associated ore bodies, leads to the conviction that even tho the ore-bearing solutions traveled outward from certain chimney channels in favorable manto sections, vein-like bodies were deposited when an open pre-mineral fissure was crossed.

3. POTOSI CHIMNEY AREA

The third arbitrarily chosen group of ore bodies will be referred to as the Potosi Chimney area.

The complicated chimney-manto system is well shown on the plan and sections (Plates No. 2, 4, & 5).

The main features presented by the Potosi chimney area are:

1. The connection of the mantos to one another
2. The association of primary ore bodies with the fissures, previously regarded by other observers as post-mineral in age
3. The occurrence of numerous favorable manto zones in the Black limestone, previously supposed to be unfavorable to manto deposition
4. The marked evidence of fissure control
5. The tendency of the chimneys to join in depth
6. The probability of the Chorro or Santo Domingo chimney

proving to be the principal channel for the ascending ore-bearing solutions.

7. The large increase in cross-section of most of the primary ore bodies over the combined cross-sections of their feeders

From the above enumerated features, it can be readily understood why the Potosi chimney unit offers an ideal area for a study of manto deposits.

The fractures have already been grouped in three general systems, the N-S, the NE-SW and the E-W. From west to east the most prominent zones of the N-S system identified within the Potosi chimney area are (1) the Chorro (2) Chihuahua (3) 'S' or Hematite (4) Potosi (5) 'M' (6) 'J' North (7) 'A' (8) Rosario (9) Tunnel (10) Dennis (11) N 30 degrees E,-'E' fissure zones.

The most important members of the Northeast system are: (1) San Lazaro (2) Santo Domingo Cave (3) 'F' 30 (4) 'R' 30 (5) 'Q' 30 and (6) Potosi Dike fissures.

The Gypsum, 'E', 'L.S.', Peru, 'N' and 'J' fissures belong to the East-West system.

The different ore bodies, both chimneys and mantos, will be described briefly with reference to the associated fissures and favorable zones which are responsible for their location.

The Chorro or Santo Domingo chimney is the largest in the district, and evidence collected during the last few years adds weight to the assumption that the ore body probably occupies the principal channel thru which the ore-bearing solutions rose. The solutions ascended thru the largest and most pronounced fractured zone of the district, formed by the intersection of the San Lazaro, Gypsum, Chihuahua, Chorro, and several unnamed fissure zones.

The upper section of the chimney lies within the boundaries of the Buena Tierra, Sin Nombre, and the Santo Domingo claims of the Potosi Mining Company, while the gentle southern pitch of the chimney throws the lower section entirely within the ground of the Potosi Mining Company. This chimney has already been mentioned as the channel to the ore bodies extending north, known as the West Mantos. Recent development leaves but little doubt that the chimney was a channel for the ore-bearing solutions that diverged at a depth not yet opened by development, and by a very irregular course finally ascended to the site of the 'G' ore body. The 'G' ore body is the feeder to the ore bodies referred to as the East Mantos.

The cross-section of the Chorro diminished as successive mantos dxtended outward. By the time the capping was reached the mineralized area was relatively small. The ore-bearing solutions rising to the capping were diverted along the contact to deposit several irregular bodies. The conditions indicate that the siliceous capping was unfavorable for replacement and that mineralization was post-capping.

Near the close of the nineteenth century a disasterous cavein occurred. It was attributed to insufficient support and greedy undercutting by the three operating companies. The collapse was, however, in part, caused by the disintegration of the limestone along the fractured zones by surface water which released large blocks of limestone. The present cross-section consequently is undoubtedly much greater than that of the originally mineralized area.

The Chihuahua and Chorro fissure zones crossed within the chimney. On the lower levels, north and south of the chimney, sulphide bodies have been encountered associated with the fissures.

The Santo Domingo Cave ore bodies extend south from the Chorro, and are related to the Chorro and Chihuahua fissure zones. Chimneys occur where the two zones cross, and also farther to the south where they are crossed by the 'B' and Santo Domingo fissures. Diamond drilling proved the Santo Domingo Cave fissure to be ore-bearing in depth.

The 'P'-Lower Sulphide chimney occurs at the zone of intersection of the L.S.-Hematite and Potosi fissures with the E-W 'B' fissure zone. The vertical Potosi fissure merges with the east dipping 'L.S.'-Hematite fracture near the 10th level of the Potosi Mine. The combined fissures below this level form one of the strongest mineral zones of the unit.

The upper part of the ore body is known as the 'P' chimney, while the lower section extending toward the north is called the Lower Sulphide body. The Lower Sulphide body is one of the most important ore bodies of the district. From its size and trend it appears probable that this mass will connect with the Chorro chimney within commercial depth. The cross-section of the 'P' chimney decreases suddenly in the Los Lamentos limestone where mantos extend out from the chimney. A part, however, continues to the capping, irregular in outline, and decreasing in cross-section above the mantos which extend outward in favorable beds.

The immense 'S' ore body extends south from the Lower Sulphide body. Mineralizing solutions evidently passed from the site of the Chorro chimney thru the Lower Sulphide section where a part was diverted to the south, and the remainder continued upward. The solutions passing upward were responsible for the 'P' chimney deposit. The diverted solutions passed thru to the site of the 'S' ore body, and deposited a series of mantos to the east.

The 'S' ore body is a group of high grade lead-zinc-silver sulphide mantos separated by lenses of low grade ore or barren limestone. The ore-bearing solutions within favorable horizons apparently worked outward from the Lower Sulphide 'P' chimney channel along the strong 'L.S.'-Potosi fissure zone, taking advantage of the cross fractures to replace laterally from the main channel.

The 'O' ore body occurs farther to the south associated with the Potosi fissure zone at the intersection with the east-west 'J' fissure. This ore body may connect with the 'S', or it may assume a chimney form and join a lower manto that has a strike toward the Lower Sulphide or Chorro chimney.

Before continuing with the southern part of the Potosi Chimney area, it is advisable to follow the path of the mineral-

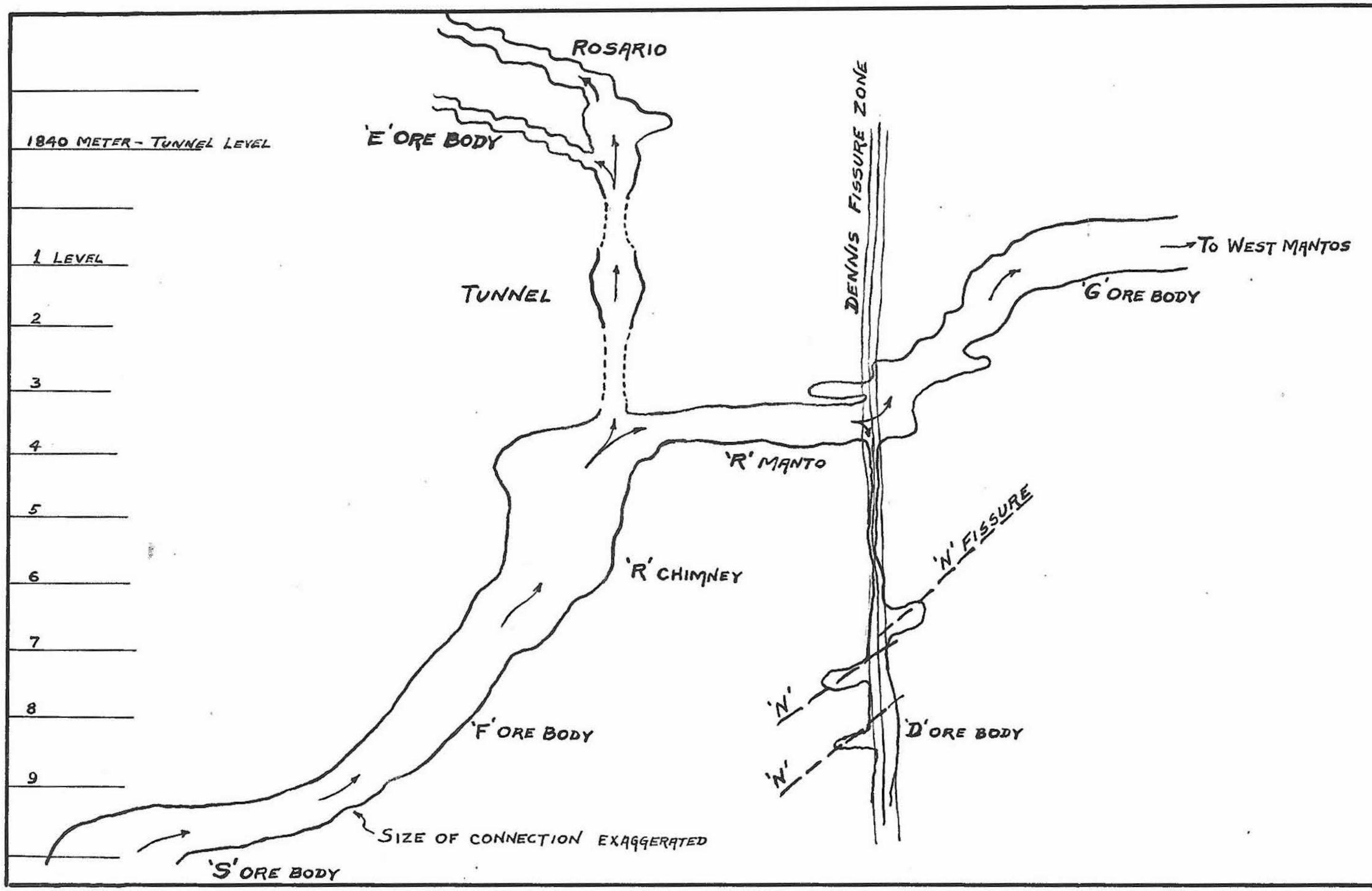


FIGURE NO. 9.

DIAGRAM SHOWING PATH OF ORE-BEARING SOLUTIONS FROM THE 'S' ORE BODY TO THE WEST MANTOS. (Not to scale) ization east from the 'S' ore body. The mineral bearing solutions passed east from the site of the 'S' manto along the 'L' fissure thru the 'S' carbonate ore body channel and deposited the 'N' ore body at the 'J' North fissure. The solutions passed east and were responsible for the 'F' and 'R' ore bodies where the 'J' North fissure is intersected by the 'F' 30 and 'R' 30 fracture zones. The Tunnel fissure zone also intersects the 'R' 30 at the site of the 'R' chimney.

A division of the 'R' chimney above the 4th level of the Potosi mine gives rise, in its minor part, to a section extending north as an inclined manto. The major part, which was diverted to the east, is known as the 'R' manto. The 'R' manto is associated with the inclined 'N' fissure. East of the Dennis fissure zone it extends upward as a chimney and then again has a manto form. The deposit east of the Dennis is known as the 'G' ore body. The ore-bearing solutions responsible for the deposit of the East or Central-Bustillos-Galdeano manto passed thru the opening now occupied by the 'G' ore body. The diagram (Figure No. 9) shows the path of the solutions from the 'S' to the 'G' ore body.

While the greater part of the ore-bearing solutions passed thru the chimney and ascended to the site of the East Mantos, the remainder continued north, in the Tunnel fissure, and furnished the metallic constituents for the T or Tunnel, the Bird, 'E', and Rosario ore bodies.

The Rosario is associated with the limestone--'capping' contact with replacement confined to the limestone. The 'R' chimney and the Tunnel ore body are connected by a leached section. A change in character of the ore from the 'S' ore body to the east will be discussed later.

A mineralized area occurs in the Dennis fissure below where it is crossed by the 'R' ore body. A vein-like deposit also occurs where the 'N' fissure crosses the Dennis. The ore-bearing solutions apparently descended and deposited minerals in the Dennis from the site of the 'R' ore body.

The 'O' has a chimney form at the intersection of the 'J' and Potosi fissure zones. Farther to the east, the 'J' fissure locates the 'Q' carbonate ore body at the intersection with the Dike fissure, and east of this body it forms the big 'Q' ore body at the intersection with the Tunnel fissure zone. The Potosi Dike cuts the 'Q' ore body.

The Dike fissure locates the 'A' Carbonate ore body at its junction with the 'J' North. The 'A' Sulphide manto occurs at the intersection of the 'A' fissure zone with the Potosi Dike fissure.

Recently the 'O' has been found to connect with the 'A' Sulphide deposit and the 'A' furnished a path for part, if not all, of the solutions responsible for the 'Q' ore body.

Evidence used in tracing the path of the mineralizing solutions include the character of the ore and the definite zoning outward from the central chimney.

A 100 foot favorable manto section lies at the base of the Los Lamentos limestone. Some of the larger mantos of the Potosi

Mine occur within this range.

A favorable manto section occurs in the Black limestone between markers No. 13, and 14. Marker 15 and the section extending 30 feet above the bed are extremely productive. Late development has shown bed No. 16 to be productive, and the most recent work indicates sections associated with markers No. 19 and 20 may prove to contain the largest mantos of the district.

4. INGLATERRA GROUP

The fourth division of the ore bodies is called the Inglaterra Group. The 'A' Sulphide ore body extends south from the Potosi claim, and connects with a series of rather thin mantos and irregular chimneys, which are small, compared to the ore bodies of the Potoxi chimney section. The production has been almost exclusively from oxidized ore.

From the 'A' Sulphide, a narrow manto extends south, then spreads east-west parallel to the general dike trend. It not only spreads laterally but extends downward in small chimney-like roots. A narrow manto extends south associated with the 'A' fissure zone, and connects with the largest body of the Inglaterra mine, the 'I'-10 chimney. The 'I'-10 chimney has a vertical range from the capping to over 200 feet into the Black limestone. The deposit spreads toward the west and follows the Inglaterra Dike fissure.

The Inglaterra Dike fissure is pre-mineral, and belongs to the NE-SW system. There was apparently some pre-mineral movement. The ore solutions, from the north, banked against the faulted limestone, and spread laterally and vertically within and along the north side of the zone. Post-mineral activity reopened the Inglaterra fissure and a dike was intruded.

The Inglaterra dike did not cut the deposit in the fissure, but surrounded and mixed with it. Subsequently this inclined dike was altered together with the enclosed material. The metallic content of the altered dike permits commercial extraction of some sections within the limits of the ore body. The dike has generally been regarded as pre-mineral, but this is erroneous.

I do not believe the mineralizing solutions ascended along the Inglaterra Dike fissure, but that ~~its course~~ they passed thru the site of the 'A' Sulphide ore body, traveled south within the Los Lamentos formation in the 'A' fissure zone, and spread vertically and horizontally in the inclined open Inglaterra Dike fissure zone.

The same interpretation is applied to the San Antonio Chico ore body which lies east and a short distance south of the 'I'-10 chimney. The San Antonio Chico ore is also vein-like in plan and section and is cut by an altered dike ~~which~~ contains low grade ore ~~within the completely altered dike~~.

5. PARCIONERA ORE BODIES

The plan of the ore bodies (Plate No. 3) shows the northern end of the West Mantos bending toward the west. The change in direction follows a minor warp or fold which strikes east-west and disappears in the vicinity of the West Mantos. The fifth group of ore bodies, Parcionera Mantos, follows the crest of this fold. Erosion has disconnected the east end of the Parcionera from the Burro Road ore body of the West Mantos.

The Parcionera is one of the oldest mines of the district. The ore bodies, excepting the chimneys to the surface, are confined to the lower 250 feet of the Bufa limestone. The ore is similar to the type found in the northern part of the West Manto.

Ore-bearing solutions responsible for the deposition of the northern part of the Mina Vieja section probably followed the fractured crest of the N-S fold, turned to the west at the site of the Burro Road ore body, followed the E-W fold, and deposited the Parcionera ore body. Toward the west, the silver content of the ores increased in proportion to the distance from the principal source chimney. The eastern part of the manto contained an oxidized ore typical of the West Manto.

The main fissures associated with the Parcionera manto have not been mapped. However, the fissures were probably tensional fractures at the crest of a fold.

One of the stopes of the Parcionera is said to be large enough to house the Cathedral of Chihuahua.

The Santa Rita ore body lies farther to the west, is related to the fold, and occurs in the same manto section as the Parcionera Manto. The siliceous ore which occurs in subordinate quantities in the West Manto and the Parcionera, forms the bulk of the Santa Rita ore.

6. ISOLATED ORE BODIES

A number of isolated ore bodies lie outside of the areas just described. Among the most important are the 'B', Western, Reina de Plata, Carmen, Peru, Carolina, Cocinera, and the Coronel-Zubiate, all shown on the map of the ore bodies (Plate No. 2). Several small ore bodies lie south of the limit of the map of which the Baltimore is probably the most important. The character of this group will be only mentioned as a detailed treatment is beyond the scope of this paper.

The 'B' is one of the so-called contact bodies; that is, the ore follows the contact of the limestone erosion surface with the capping. Contact ore bodies are usually irregular and show a lack of fissure control. The 'B', however, while following the contact with deposition in both the capping and limestone, is governed by N-S and NE-SW fissures. The rake of the 'B' ore body is toward the Chorro and it probably represents the top of this chimney. The ore is of two types, one a high silver-low lead and the other the normal lead-silver carbonate ore.

The Peru and Western ore bodies are very similar and both occur in the Los Lamentos limestone. They are narrow, thin bodies following fissures, and consist of two classes of ore, the high silver and the lead-silver carbonate types. These two deposits may connect along a N-S fissure.

The Reina de Plata is also an irregular contact-body. Contact ore bodies usually have a high silver content and such is the case of the Reina de Plata.

The Coronel-Zubiate chimney area is by far the most important of the isolated bodies. This deposit is a chimney with several mantos extending outward in favorable zones of the Bufa and Intermediate limestone. The lower part of the chimney is in contact with a fault filled by a post-mineral dike. A northern extension has not been found, altho it is very probable that so strong an ore body is connected with the central Potosi chimney area.

The two important manto producing areas of the Coronel-Zubiate appear to be allied with small warps or folds. The chimney was worked by the Spaniards. The ore in the upper part was a siliceous silver type. At depth the normal lead-silver type occurs intermixed with the siliceous silver ore.

The numerous other small isolated ore bodies are not pertinent to this treatment, and consequently will not be discussed.

ORE AND GANGUE MINERALS

A complete study of the many minerals associated with the ore deposits of the Santa Eulalia district lies outside of the scope of the present paper. W. F. Foshag has collected much material in the district, and has, in preparation, a paper dealing with the mineralogy of the district together with that of several other important manto deposits.

The following list includes many minerals which have had their identification checked by Foshag from his collections. A number of identifications were made during this study, and the list is enlarged by additions from the group given by Prescott[1]. Undoubtedly, the list will be further increased by additional mineralogical studies.

List of Minerals

Sulphur	Pyrolusite
Silver	Psilomelane
Gold	Wad
Galena	Calcite
Pyrite	Ankerite
Sphalerite (Marmatite)	Dolomite
Pyrrhotite	Aragonite
Arsenopyrite	Rhodocrosite
Chalcopyrite	Barite
Proustite	Siderite
Argentite	Gypsum
Pyrargyrite	Azurite
Realgar	Malachite
Marcasite	Epsomite
Greenockite	Mirabilite
Anglesite	Quartz
Cerussite	Chalcedony
Brochantite	Copiapite
Calamine	Alunogen

(1) Prescott, Basil--The Main Mineral Zone of the Santa Eulalia District, Chihuahua, Mexico-Tran. A.J.M.E. Vol. Ll. 1915, pp. 57-99.

Smithsonite
Chalcocite
Hematite
Limonite
Jarosite
Plumbojarosite
Magnetite
Wulfenite
Pyromorphite
Melanterite
Halite
Hedenbergite
Knebelite
Fayalite
Ilvaite
Forsterite

Goslarite
Turgite
Manganite
Fluorite
Cerargyrite
Mimetite
Natronite
Willemite
Rhodonite
Tremolite
Hisingerite
Uralite
Chlorite
Hydrozincite

The most notable feature of the above list is the presence of the iron and iron-magnesium silicates, and the absence of calcium silicates, altho the deposits occur in limestone and are some distance from even a hypothetical body of intrusive rock.

Table No. 7.

ORE AND GANGUE MINERALS OF THE PRIMARY ORES

Group I Iron silicate ores.	Group II Zinc-lead ores.	Group III Siliceous-silver ores.
hedenbergite		
forsterite		
knebelite		
fayalite		
ilvaite		
magnetite	(magnetite)	
quartz	quartz	quartz
chalcedony		
fluorite	fluorite	
calcite	calcite	calcite
barite	barite	
dolomite	dolomite	dolomite
pyrite	pyrite	pyrite
pyrrhotite	pyrrhotite	
arsenopyrite	(arsenopyrite)	
chalcopyrite	(chalcopyrite)	
marmatite (Fe, Zn S)	marmatite	(marmatite)
galena	galena	galena
proustite	proustite	proustite
argentite	argentite	argentite
pyrargarite	pyrargarite	pyrargarite
(gold)		

Minerals in parenthesis occur in minute quantities.

Group I

Iron Silicate Ores

The ores of the iron silicate class have commonly been referred to as those of the High Temperature Stage because of the remarkable association of a number of supposedly high temperature iron silicate gangue minerals with the ore minerals. The current opinion is that this class of ore was deposited first and that its deposition was separated by a time interval, during which fracturing took place, from the deposition of the ores of the zinc-lead class. The writer believes, however, this stage marks only the beginning of a continuous cycle of mineralization which, with changing physical and chemical conditions of the ore-bearing solutions and the limestone, would easily account for the change in character of the ores.

The chief gangue minerals of the ores of this group are the supposedly high temperature iron silicate minerals; namely, hedenbergite, fosterite, fayalite, knebelite, and ilvaite, which, together with magnetite, compose over 50 per cent of the ore. These gangue minerals precededthe sulphides in order of crystallization. The remaining gangue minerals, quartz, chalcedony, fluorite, calcite, and barite occur in subordinate amounts and were deposited over a long period. Pyrite was the first of the sulphide minerals, followed by pyrrhotite (the most abundant sulphide), arsenopyrite, chalcopyrite, marmatite, galena, and argentite. Hypogene enrichment introduced the proustite and pyrargarite.

Such a combination of iron silicate minerals is ordinarily looked upon as indicative of contact metamorphism or of deposits resulting from concentration in a molten magma. However, the silicates and associated sulphides are found in the upper part of the mine, hundreds of feet above the zinc-lead class ore bodies, and at least several thousand feet removed from any igneous mass which might have supplied the mineralizing solutions. The country rock, limestone, shows no evidence of metamorphism and the lime-rich silicates which one would expect are missing. This is the only occurrence, to the writer's knowledge, where this combination of iron silicates occurs in an unmetamorphased limestone distant from any known intrusive body.

Deposits of this class vary in form and size. The most common occurrences are tabular, vein-like deposits, several meters in width. Some have been stoped to 500 feet below the capping. The ore is usually well banded parallel to the walls, whether the ore bodies are horizontal or vertical. There is no gradation of the ore into the limestone.

This class of ore is limited in occurrence. Unstoped remnants occur immediately north and south of the Chorro chimney, notably in the southern part of the Velardena claim, the 'S' ore body, and upper 'P' chimney. Small remnants occur even farther removed from the Chorro.

Apparently ore-bearing solutions ascended in the well-fractured zone occupied by the Chorro chimney. Upon reaching the upper elevations, the iron-rich siliceous solutions worked outward along the most open fractures and deposited the banded vein-like bodies. Intense fracturing in the brittle, favorable horizons produced a semi-brecciated zone. The ore solutions surrounded the broken limestone blocks and, in part, replaced them producing manto-like bodies. The iron silicate ores apparently extended over a larger area than formerly believed; ~~and~~ the greater part of them have been replaced by the zinc-lead ores.

A transitional change from the iron silicate class to the zinc-lead class ores occurred as deposition continued. A lowering of the temperature alone could have produced this change, but the cycle was apparently complicated by modifications in the character of the ore-bearing solutions and the physical conditions of the limestone.

Oxidized Ores of Group I

Susceptibility of the iron silicate class ores to oxidation is indirectly proportional to the amount of iron silicates present. The density and texture of the ore containing abundant silicates is not favorable to rapid oxidation. The greater part of this type of ore contained less than 50 per cent silicates and was susceptible to oxidation.

The pyroxene usually breaks down to uralite, a soft brownish-green amphibole in which the crystals, when distinct, retain the form of the original mineral but have the cleavage of amphibole. Hisingerite is found in the partially oxidized material, usually intergrown with secondary dolomite and has a botryoidal structure inclosing unoxidized material. Where the silicates form a subordinate part of the ore and oxidation is complete, the product has the appearance of the so-called typical oxidized ore of the district. Such material contains an extremely large amount of iron oxides and silica, and oxidized lead, zinc, and silver minerals. R. J. Colony, in a private report submitted to the Potosi Mining Co., found an abundance of iron oxides retaining a structure suggestive of former contact-metamorphic silicate minerals.

Primary magnetite is distributed through the oxidized material. It is interesting to note that the silver appears to occur independently of lead and bears no constant ratio to that metal in the primary or oxidized ore. Quartz is found impregnated with iron, lead, and silver oxide minerals.

Group II

Zinc-lead Ores

The change in character of the ore-bearing solutions, by reduction in temperature together with other physical and chemical changes, affect the character of the deposited material. The iron silicate gangue minerals, magnetite, arsenopyrite, and chalcopyrite are almost totally absent in the group of minerals that form the zinc-lead ores, or normal sulphide ore of the district (Table 7). During deposition of the zinc-lead ores, the fall in temperature of the solutions continued slowly.

Absorption of heat by the country rock at the beginning of mineralization produced rapid deposition of the high temperature minerals and sharp contacts with the country rock. There was no contact metamorphism, and very little replacement.

The zinc-lead ores consist chiefly of zinc, lead, and iron sulphides. They vary from ores containing a large zinc sulphide content to those with a low zinc sulphide and a large lead sulphide content. There is a definite zoning, horizontal, vertical, or both, away from the site of the Chorro chimney. A decided increase in the zinc in ratio to the lead is noted as the Chorro is approached.

Ores of this group are predominantly mixtures of pyrite, pyrrhotite, marmatite, and galena, and gangue minerals, quartz, fluorite, calcite, barite, and high temperature silicates. Hypogene enrichment introduced silver minerals into ores of this character. The principal silver minerals are proustite, and pyrargarite.

Aside from the ~~conclusive~~ evidence offered by the primary bodies concerning the original structure and character of manto deposits, they offer an unusual opportunity to study zonal arrangement, overlapping, and telescoping of minerals.

The zinc-lead ores have replaced the greater part of the deposits of the iron silicate ores. The replacement has been partial in some places, complete in others. In general, where the ore bearing solutions followed the same channels which existed at the beginning of the cycle, a complete replacement occurred; and, if the solutions found that certain fractures and favorable horizons ~~that~~ were more open and susceptible to replacement than the original channels, they followed the latter.

Replacement deposits associated with parallel fractures in different favorable manto horizons or diverging fractures in the same, may have a very different composition at points equidistant from the source.

The lowest zone developed is the basal part of the zinc-lead class. The ore is predominately a mixture of marmatite, galena, pyrite, and pyrrhotite. The gangue minerals are quartz, fluorite, calcite, barite, and a small amount of iron silicates. Magnetite occurs in small quantity. These ores occur exclusively in the developed sulphide zone in the lower part of the Potosi Mine. Oxidized bodies of this type have not been found. Oxidized stringers of zinc-lead and iron minerals extend outward from the sulphide bodies. These pinch away from the ore body. The metallic content of the oxidized stringers indicates comparatively little migration of the zinc.

The zinc content of the ores rapidly decreases above the 10th level of the Potosi Mine. In the upper ores, the ratio of lead, iron, and silver to the zinc is high. The gangue of the upper zone is more siliceous than that of the lower zone and magnetite and the iron silicate minerals are less abundant. Large bodies of sulphide ore are rare above the 10th level. The sulphides show a predominance of galena over marmatite and pyrite, with a quartz, fluorite, barite, and calcite gangue. Pyrrhotite is rare.

Oxidized ores of the upper zone of the zinc-lead class constituted the bulk of the ore extracted in the district prior to 1920. The West Mantos, with the exception of the iron silicate body previously mentioned, contained ores of this class. The oxidized mantos and upper parts of the chimneys of the Potosi Mine also belong to the upper part of the zinc-lead zone. It has a vertical range of over 1500 feet. Large bodies of oxidized zinc do not occur associated with the oxidized ore bodies. If the composition of the primary ore was the same as that of the zinc-lead sulphide ores below the 10th level, it seems improbable that the zinc was almost completely removed during oxidation.

The oxidized ores are roughly-bedded heterogeneous mixtures of anglesite, cerussite, iron and manganese oxides, fluorite, calcite, quartz, and gypsum. The ore is, in general, a rather porous, friable mass of siliceous iron oxides and lead carbonates. Residual nodules of galena are commonly inclosed by anglesite. The ores, aside from the silver content, are similar to those of the Los Lamentos district.

Both sulphide and oxidized mantos have well developed hilos. In the sulphide bodies, the hilos are thin blankets extending outward from the thicker manto section. The hilos also extend outward from the ore-bearing caves which are associated with the oxidized mantos. Migration of the metallic content is well exemplified in the banded oxidized mantos and in the oxidized portions of chimneys.

A remarkable feature of the oxidized mantos is the rather constant character of the metallic content for individual ore bodies; a condition well emphasized by Prescott. Local variation occurs, however, and is important for the interpretation of the character of the primary ore bodies.

Group III

Siliceous-Silver Ores

Siliceous silver ores form the third group of ores of the district. The ores were deposited from rather cool, silver-ore-bearing solutions. Hypogene ores of this group are rare. However, remnants of the primary ores occur in the 'G' body. The hypogene ore is predominately a mixture of pyrite and quartz, with subordinate amounts of proustite, pyrargarite, argentite, galena, and occasionally segregations of sphalerite.

Ore bodies of this class are, in general, farther removed from their source than deposits of the iron silicate and zinc-lead ores. Deposits are also found near the chimney, and where they cut ores deposited during the earlier part of the depositional period. This has led some investigators to set up numerous stages of mineralization separated by time intervals. The ores of the district, as a whole, indicate continuous ore deposition.

The third type of ore is that of the so-called silver zone. The ore-bearing solutions during this period of the deposition not only formed replacement bodies, but also percolated or circulated thru the previously deposited bodies and the porous limestones, and, in doing so, effected hypogene silver enrichment. The oxidation of the hypogene silver minerals in the limestone produced the so-called lime silver or pay lime ore bodies.

Oxidized Ores of Group III

Oxidation of ore of this class proceeded almost to completion in the hilos as well as the mantos. The oxidized ore is a porous, heterogeneous mixture of silver-bearing, siliceous, iron oxide in calcitic gangue. It is rather soft and contains more gypsum than the other classes of ore described. The variation in the silver and lead contents indicate the variation of the character of the deposits. The ores of this class were the highest-grade silver ores of the district.

OXIDATION

Oxidation, in addition to oxidizing the ores, has changed the appearance of the deposits to such an extent that some early investigators assumed that the ores were deposited in pre-existing solution chambers.

The major part of the ore extracted was from the oxidized mantos. The bedded manto ore usually occurs in the floor of the ore-bearing caves. Such caves do not exceed, in area, the original extent of the ore and are not everywhere present above the ore.

Ore-bearing caves were formed by removal of limestone below the ore by the reaction of the acid solutions, generated during the oxidation of the sulphides, on the limestone and by the removal of the dissolved material by circulation. This was accompanied by subsidence of the oxidized ore. Therefore, the ultimate position of the oxidized deposit is considerably lower than the position of the primary ore body. The subsidence left an open space above the ore; collapse of the roof followed and this continued until a stable arch was established. The blocks of limestone, from the roof, mingled with the oxidized ore and generally occur also as a chaotic cover

over the ore.

The site of the hypogene deposit is usually marked by the position of the hilos. These thin blankets, or ribbons, of ore originally extended outward from the mantos. They were not as susceptible to oxidation as the thicker manto deposits. The limestone enclosing them is usually more compact and unbroken than that enclosing the mantos, and this retarded oxidation and the removal of the limestone from beneath the hilos. The hilos, accordingly, were left stranded above the oxidized mantos. Oxidation of the hilos at Santa Eulalia has been more complete than in the Los Lamentos district, probably because the hilos are less prominent at Santa Eulalia.

The final step in the oxidation process, in connection with the mantos, was the deposition of a calcitic shell over the ore in the cave. Beautiful stalagmites, stalactites, and gypsum were deposited as parts of this shell. Indeed, to one entering an unmined ore-bearing cave, there is little to suggest the presence of large oxidized ore bodies beneath the calcite crust.

Barren-caves are also a consequence of oxidation. These are developed along the main channels of circulation of the oxidizing solutions. Their formation resulted from solution of the limestone by the acid waters developed during oxidation. In the Los Lamentos district, the barren-caves are parallel to the main ore bodies and indicate that the fracture system which controlled the hypogene mineralization was also open during oxidation. In this district, however, the Northeast fracture system was the most prominent during oxidation.

Barren-caves have greater height than breadth; the majority are nothing more than enlarged fissures. They are also lined with gypsum and calcite. Ore has sometimes been washed into the barren-caves, and occasionally secondary zinc minerals have been deposited in them.

The circulating meteoric solutions probably first attacked the pyrite and pyrrhotite generating sulphate and sulphuric acid. The ferrous sulphate yielded hydrous iron oxides and more sulphuric acid. The zinc sulphide was then attacked, and lead sulphide was, in turn, affected.

Iron and zinc compounds are migratory compared to those of lead. The evidence, however, does not indicate the removal of the zinc compounds, but that the sulphide ores were of nearly the same composition as the oxide ores. Migration is well demonstrated by the presence of iron oxides in the innumerable fissures, the bedded oxidized ores of the mantos and chimneys, and the manganese stained limestone. Thin beds of mixed zinc and iron oxides usually occur at the bottom of mantos and sometimes along the roof of ore-bearing caves between the limestone and the stalactitic lining. Mixed iron oxides and lead carbonates occur as beds or layers above the thin oxidized zinc deposit on the floor.

A bed of very pure cerussite is found above the iron oxides in the lead-silver and silver-lead ore bodies. The cerussite is usually overlain by a bed of gypsum, which, in turn, is separated from the open cave by a hard calcite shell. It is common to find the sequence of the bedded ores repeated; indicative of two primary mantos separated by a barren or low-grade lense removed during oxidation.

The siliceous-silver ores lack the well defined bedding characteristic of the lead-silver and silver-lead ores. The siliceous-silver ores occur as a loosely mixed, siliceous-iron oxide with a gypsumcover separated from the cave by dense calcite.

Oxidized lead ore is separated by a deposit of ferruginous material from a thick body of oxidized zinc ore in the upper Chorro chimney. The zinc ore was underlain by sulphides of the high lead-low zinc class. The upper part of the 'P' chimney shows prominent banding. An oxidized silver ore, with a low lead content, occurred in the upper part underlain by a silver-lead sulphide ore. A fracture cutting the chimney then allowed oxidizing waters to attack the sulphides below; this yielded a deposit of lead carbonate ore with silver content equal to that found in the normal lead-zinc sulphides. Below this zone, is an oxidized zinc ore which passes with a sharp contact into the normal lead-zinc sulphide ore.

During oxidation, manganese was leached from the sulphides and deposited thruout the porous limestone as manganese oxide, carbonate, or silicate. The intensity of the 'painting' depends upon the character of the limestone and hence, cannot be used as a guide to ore bodies.

The volcanic capping had been stripped from parts of the district before the close of the oxidizing process, if not earlier. The depth of oxidation varies thruout the district. The greatest depth is in excess of 1600 feet, while at other points where a thick capping occurs, oxidation extends only 700 feet below the capping.

GRADE OF THE ORES

Ore deposits with the vertical and horizontal range exhibited by the deposits of the Santa Eulalia district would naturally be expected to show a great range in the grade of the ores.

The iron silicate ores occur in tabular, vein-like, vertical, and horizontal bodies closely associated with the Charro chimney. The Jean Cave ore body and its extension in the Velardena claim show vertical banded bodies of this type, while horizontal bedded deposits are found within the 'S' ore body and the upper 'P' chimney. All available evidence points toward a much wider original distribution of the ore and to almost complete replacement by ores of a different character.

The high zinc-lead zone of the zinc-lead class of ores occurs only in a primary state, excepting oxidized seams in fissures near the ore bodies. It is exemplified by the chimney and manto deposits below the 11th level of the Potosi Mine. It is, at present, the most important ore of the district.

The so-called normal sulphide ore of the district is represented by lead-zinc silver ores occurring near the 10th level of the Potosi Mine, and contains about equal amounts of lead and zinc.

Primary ores of the high lead-low zinc zone are rare. The oxidized ores of this class occur in large bodies, just above the normal sulphide ores of the Potosi chimney area.

They grade upward into the ores of the lead-silver zone.

The ore of the lead-silver zone occurs, with very few exceptions, in an oxidized state. Commercially, the ores of this type have been second in importance during the past. The oxidized ores on the upper part of the Potosi Mine and the West Mantos represent this zone. The Parcionera and Inglaterra ore bodies also were of this class.

The siliceous silver ores, the silver zone, form the deposits of the East Mantos, the upper levels of the Zubiate, and the capping ore bodies. With few exceptions, bodies of this class are completely oxidized.

The ores, in general, exhibit a zoning outward and upward from the Chorro chimney, and this leads to the conclusion that the site of the Chorro chimney was the channel followed by the ore-bearing solutions from depth.

The following table gives average assays of the different classes of ores discussed above.

Table No. 8.

SULPHIDE ORES

(Average assays for the different classes)

	Assay		
1.	Ag 5. - 20. oz. Pb 0.2 - 2.5 % Zn 0.5 - 4. % Fe 35. - 45. % SiO_2 10. - 15. % As 1.5 - 2.5 % Mn 3. - 5. %	Iron silicate ores. (High temperature stage.)
2.	Ag 8. - 10. oz. Pb 7. - 10. % Zn 10. - 16. % Fe 25. - 35. % SiO_2 2. - 7. % As 0.5 - 1.5 % Mn 0.5 - 1.5 %	Zinc-lead ores (zinc-lead zone). This class forms the high zinc zone. It is represented by the sulphide deposits below the 11th level of the Potosi Mine. Referred to as the zinc-lead zone.
3.	Ag 8. - 12. oz. Pb 10. - 15. % Zn 7. - 10. % Fe 20. - 30. % SiO_2 2. - 10. % As 0.5 - 1.5 % Mn 0.5 - 1.5 %	Zinc-lead ores (lead-zinc zone). These occur higher in the zonal arrangement than the zinc-lead zone in which the zinc predominates over the lead.
4.	Ag 15. - 25. oz. Pb 15. - 30. % Zn 2.5 - 5. % Fe 20. - 30. % SiO_2 5. - 30. % As 0.5 - 1.5 % Mn 0.5 - 1.5 %	Zinc-lead ores (lead-silver zone). These ores occur thruout the district, altho, usually in an oxidized condition. The sulphide bodies are erratic in assay.
5.	Ag 25. -150. oz. Pb 3. - 7. % Zn tr. - 3. % Fe 10. - 35. % SiO_2 10. - 35. % As 0.5 - 1.5 % Mn 0.5 - 5. %	Siliceous-silver ores (silver-lead zone). Siliceous-silver class. Very few occurrences of fresh sulphides. Silver sulphides identified are proustite, argentite, and pyrargyrite.

OXIDIZED ORES

Assay (con't.)

			Description
6.	Ag	5. - 20. oz.	Oxidized iron silicate ores.
	Pb	0.2 - 2.5 %	
	Zn	tr. - 3. %	
	Fe	25. - 40. %	
	SiO_2	10. - 15. %	
	As	1.5 - 2.5 %	
	Mn	3. - 5. %	
7.	Ag	25. -300. oz.	Oxidized siliceous-silver ores (silver-lead zone).
	Pb	3. - 7. %	
	Zn	tr. - 3. %	
	Fe	10. - 35. %	
	SiO_2	15. - 35. %	
	Ca	5. - 15. %	
	As	0.5 - 1.5 %	
	Mn	0.5 - 4.5 %	
8.	Ag	5. - 50. oz.	"Pay Lime," i.e. Limestone impregnated with silver sulphides and the silver minerals completely oxidized.
	Mn	1.5 - 6. %	

GENESIS OF THE ORE DEPOSITS

The mode of origin of manto deposits is taken up in another part of this thesis, (pp.). As has already been stated, it is thought that the ores of the Santa Eulalia district were all formed during the same general period of mineralization, and that they have a common origin. The similarity of the ores, the general continuity in strike, and the actual tracing of the ores of one group thru a transition to those of another group suffice to prove this assertion. Altho the origin of the ore-bearing solutions is not readily susceptible to positive proof, there can be no reasonable doubt that the ore-bearing solutions were hot magmatic waters, and that the original source of the solutions was a deep seated intrusion of probable monzonitic or dioritic composition.

The solutions forming the earliest deposits must have been at a moderately high temperature and pressure, and the minerals of these deposits are the rare, heavy iron silicate gangue minerals which almost always occur in igneous or metamorphic rocks, in pyrometasomatic, or in hypothermal deposits. The Santa Eulalia deposits contain the only known occurrence of fayalite, ilvaite, knebelite, fosterite, and hedenbergite associated with a metasomatic deposit in limestone, and several thousand feet removed from any probable igneous mass. The lime-bearing silicates, commonly associated with such a deposit in limestone, are almost totally missing. The remaining gangue minerals, quartz, chalcedony, fluorite, calcite, barite, and dolomite were deposited over a long period. The sulphide minerals associated with the silicate ores, those of group I, are chiefly pyrrhotite, pyrite, marmatite, galena, arsenopyrite, and chalcopyrite. The distribution of this class of deposit has already been mentioned (pp. 90-93). The total lack of evidence of metamorphic action on the country rock, the distribution and character of the ores, to the author, suggests that the high temperature silicates were probably deposited at a much lower temperature than commonly believed.

The mineralogic character and distribution of the succeeding groups of ores, the ores of Group II and III, have been discussed in detail (pp. 93-100).

The deposits are zoned upward and outward from the site of the Chorro chimney.

The interpretation of the original conditions ~~are~~ is complicated by the numerous evidences of local ruptures during deposition. The general composition of the mineralizing solutions, so far as can be judged from the minerals they have formed, leads to the same conclusion. Local differences in the deposits are apparently due in a large part to the different physical conditions under which they were formed.

Outward and upward from the source of the solutions, the temperature and pressure decreased more and more; ~~and~~ the composition of the solutions, and the deposited material changed accordingly. It is also evident that as the region gradually lost its heat, the temperature at a given place decreased and deposits which were formed at lower temperatures were occasionally superimposed on and partially or totally replaced those previously formed at higher temperatures. The latter accounts for the hypogene enrichment of the higher temperature deposits by the lower temperature silver minerals.

The solutions were also magnesium-bearing. The deposited magnesium minerals were altered during oxidation and locally effected dolomitization.

The primary deposits were massive replacements consisting chiefly of metallic sulphides with a small amount of gangue. To a small extent, the sulphides filled fissures, but for the most part, they were deposited by replacement without the prior development of open, empty spaces.

Fissuring of the limestone is essential for the deposition of important ore bodies. Certain beds in the limestones were much more susceptible to fissuring than others, and where fissures cut such layers, a strong brecciated zone was produced while in the adjacent beds, the fracturing may have been relatively 'tight'. The brecciation of the favorable beds near fissures and slight movement along bedding planes of the bounding layers produced zones for the lateral passage of ore-bearing solutions and the subsequent manto type replacement deposits.

Intersecting zones of fissures produced broken areas affecting channels for the passage of mineralizing solutions from depth to the favorable horizons, ~~and~~ The replacement produced the chimney deposits.

GEOLOGY AND ORE DEPOSITS

OF THE

MAPIMI DISTRICT

Durango, Mexico

by

J. WILFRED PATTERSON

CONTENTS

PLATES IN FOLDER

MAPIMI DISTRICT, DURANGO, MEXICO

Introduction

This is the third and last of a series of papers on the Manto Type Limestone Replacement Deposits of Northern Mexico. The deposits described in the preceding papers occur in districts in which the structure was comparatively simple. At Mapimi, however, the ore bodies are found associated with a very complicated structure.

The Mapimi range is composed of folded Lower Comanchean sediments and of two classes of intrusive rocks. The ore deposits lie within an intensely deformed zone which borders the northeast front of the range. Pre-mineral deformation had a pronounced influence upon the form and distribution of the deposits. The ores show a zonal distribution. An intrusive mass of granodiorite exists below the deposits, and it was apparently the source of the ore-bearing solutions. The dioritic dikes and stocks are post-mineral.

ACKNOWLEDGMENTS

The writer is indebted to Dr. L. D. Ricketts for making possible this study and for his suggestions and criticisms.

Especial thanks are due to Dr. F. L. Ransome of the California Institute of Technology who has supervised this work and critically discussed its problems. Thanks are also due to the Board of Trustees, Dr. John P. Buwalda, and Mr. Rene Engel of the California Institute of Technology.

The entire staff of the Mapimi Unit of the Compania Minera de Penoles, S. A. have aided the study by ready and courteous co-operation. All facilities for underground work, maps, and assistance of various kinds were cheerfully furnished. Appreciative acknowledgment is made to Messrs. W. H. Triplett, W. H. Holcomb, and J. P. Savage. Mr. Triplett patiently outlined his views as to certain elements of the geologic structure.

SITUATION

The Mapimi silver-lead district is situated in the northeastern corner of the State of Durango, Mexico. The ore deposits are within a vigorously deformed belt along the northeast slope of a short, isolated, north-south trending mountain range that risesabruptly above the Bolson de Mapimi.

The mines are located at Ojuela, a town 10 kilometers south-southwest of Mapimi. Ojuela is on a small, slightly tilted, overthrust block of limestone that presents precipitous faces toward the south and east. From Mapimi, a 30-inch gauge railroad runs south 4 miles to El Cambio. A rack-road with a 7 to 14 per cent grade, 2 miles in length, connects El Cambio with Ojuela. A narrow gauge railroad connects Mapimi with Bermejillo, a station on the National Lines of Mexico, 30 miles to the east.

Torreon, Coahuila, an important smelting, commercial, and railroad center is 25 miles south-southeast; and the Velardeña district lies 50 miles south of Mapimi.

The location of the Mapimi district is shown on the index map (fig.1).

FIELD WORK

The study of the Mapimi district was carried on during the summer of 1928. The base for the geologic map accompanying this paper is a part of the topographic and geologic sheet of the Sierra de Mapimi, prepared by Spurr, Cox & Co. in 1910. The geologic sections were prepared by W.H. Triplett

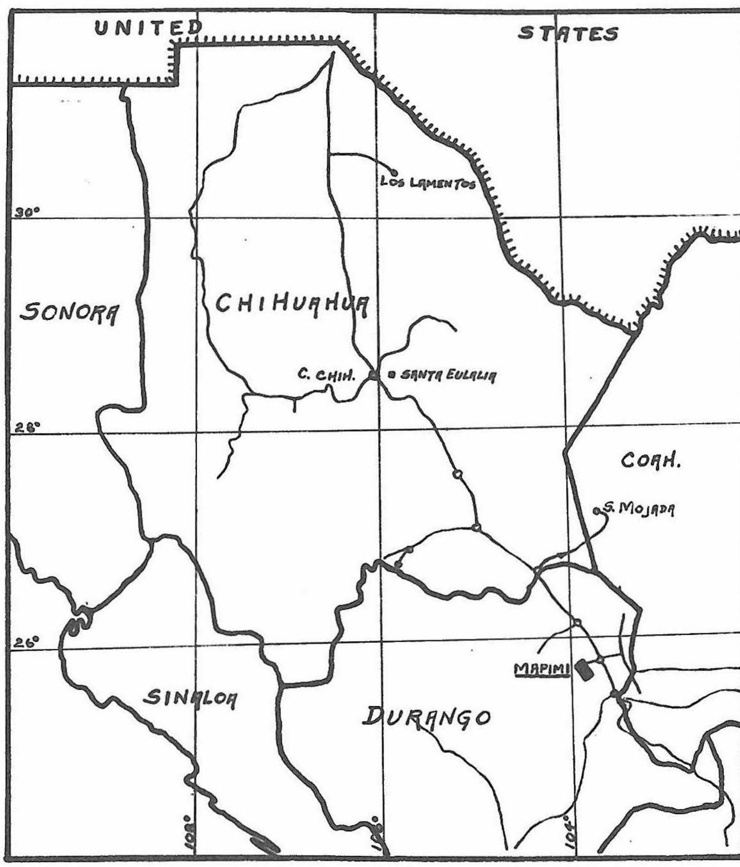


Figure 1. Index map showing the location
of the Mapimi district.

of the Cia. Minera de Peñoles, S.A.

Triplett's sections were checked on the surface and underground during this study. The interpretation of the stratigraphy and structure is not in accord with that of Spurr,[1] as will be shown later.

HISTORY

The town of Mapimi was founded in 1598 by the Spaniards near a spring at the base of the Sierra de La Bufa de Mapimi. It became one of the principal stops for water on the desert road, 'Camino Real,' between Mexico City and Chihuahua. Mapimi became a thriving smelting center and remained an important town until the removal of the smelters to Torreon. At the present time, it is in a decadent state.

Mapimi is the oldest mining district in the State of Durango. The ore bodies were discovered late in the fall of 1598. The first ore body to be worked was the Ojuela, which outcrops on the side of the cliff below the suspension bridge from the town of Ojuela to the Socavon shaft (fig.2).

Spaniards worked the mines with great success from the year of discovery until Mexico seceded from Spain. Mexicans obtained possession of the mines in 1821 and attempted to exploit the deposits but had little success. From 1867 to 1884, the district was almost abandoned.

(1) Spurr, Josiah E., The ore magmas, vol. 1, pp.202-217, 1923.

Figure 2. View of the town of Ojuela and the suspension bridge between Ojuela and the Socavon shaft. The Ojuela ore body outcrops below the bridge.

From 1884 to 1890, the mines were worked without legal authority by 'gambucinos'. Foreign capital entered the district during the last decade of the nineteenth century and activity was revived. The various foreign companies met with little success and finally abandoned or sold their rights to the Cia. Minera de Penoles S.A. After several unprofitable years, this company discovered high-grade extensions of the Ojuela ore body. The Penoles Company controls the district at present.

The Ojuela mines are among the deepest in Mexico. The Ojuela, the discovery ore body, has been worked for over 325 years and is now one of the largest producers in the district.

Very few scientific or technical papers[1] have been

1. Bennet, J. F., Diamond Drilling at Mapimi Mine and Quarry E & M. J. 85, No. 14, (April 4, 1908). p.718.

Rice, C. T., Mines of Penoles Company, Mapimi, Mexico--I & II--E & M. J. 86, No. 748, (Aug. 15 & 22, 1908) pp.309-314 & 373-374, 12 figs.

Villarello, J. D., Le Mineral de Mapimi, Guide excurs. X Congr. Geol. Int. Mexico, 1906, XVIII, 18, p.2.

Villarello, J. D.--The Mapimi District--Min. World 31, No. 1, July 3, 1909, pp. 62-63, 1 fig.

Naumann, E.--Ueber Reisebeobachtungen in Mexico--Z. D. G. G. 50 (1898)--(Verh. d. Gestello) pp.106-109.--Z.prakt. Geol. 7, 1899, Juli, p.260 (Knisch).

Prescott, Basil. The Underlying principles of the limestone replacement deposits of the Mexican province; E & M. J.P. Vol. 122, ~~pp. 122~~, pp. 247, 1926.

Spurr, J. E. Ore Magmas, Vol. I, pp.202-214, 264-267 1923. Vol. II. pp.830-832.

published on the Mapimi district, which is surprising in view of its large production of lead and silver, and its long life.

GENERAL REGIONAL SETTING

The Mesa Central (1) with the limiting Sierra Madres forms the largest physiographic unit of Mexico. This province covers two-thirds of the land surface of the Republic. The Plateau, as it is commonly called, increases in elevation south from the U. S. International border.

The Bolson de Mapimi is the largest undrained basin of the Plateau, and it covers the southeastern part of Chihuahua, the greater part of Coahuila, and northern Durango. The lowest point of the Mesa Central occurs within this depression. The general surface of the Bolson de Mapimi is broken by numerous short, steep mountain ranges which rise abruptly above the floor of the basin and have, in general, a north-northwest trend.

The Sierra de La Bufa de Mapimi is one of these ranges. It has a general northwest trend, and lies approximately in latitude, 25 degrees 50' north and in longitude, 103 degrees 50' west.

Resemblance of the region to the Great Basin of the

(1) The reader will find detailed descriptions of the Mesa Central Province in the papers on the Los Lamentos and Santa Eulalia districts.

United States is shown by the repeated troughlike depressions between the folded and faulted mountains and by the closed drainage system. Altho the volcanic accumulations are numerous, they do not approach in magnitude those of the Great Basin region.

The folding and faulting of the Comanchean sediments present an extensive field for structural studies. Recumbent folds are common.

Intense overfolding to the northeast occurs 15 miles to the southwest in the Sierra Cadena, separated by a troughlike valley from the Sierra de La Bufa de Mapimi. The Sierra Cadena is 37 miles long and displays repetition of the stratigraphic section found in the Bufa de Mapimi. Both sierras slope steeply to the southwest and present a scarp to the northeast.

The long El Cambio range borders the trough valley east of the Mapimi range. East of the El Cambio range, another valley, 13 miles wide, is bounded on the east by the short, southwest-trending Sierra de Bermejillo.

The elevations of Bermejillo and Mapimi are respectfully 3700 and 4240 feet. Ojuela with an elevation of 5350 at the patio is 1100 feet above the valley. The Bufa, the highest peak of the range, rises to an elevation of 8225 feet.
The mine and geologic maps are based on an assumed elevation of 1000 meters at the collar of the Tiro Norte No. 2 (North Shaft No. 2).

STRATIGRAPHY

The rocks of the Mapimi district, excluding the unconsolidated Quaternary wash, are predominately a series of limestones and intercalated shales cut by intrusive masses and dikes. The sedimentary formations are of Comanchean age. They were vigorously deformed during the Tertiary mountain-building period.

The limestones, in general, contain very little magnesia. Exceptions are the two dolomitic bands in the Ojuela limestone formation and the dolomitic shells that enclose some of the oxidized ore bodies. Such shells are not found around the hypogene ore bodies. The introduction of magnesia was accompanied by a modification of the texture of the limestone, and the dolomitized rock is often referred to as <u>recrystallized limestone</u>.

All the limestones are fossiliferous, altho the fossils are more abundant in certain zones than in others. In some of the limestones, the beds are thin and sharply defined; in others, the layers are massive and have indistinct parting planes. The prevailing color of the weathered limestone is light-brown to a light-gray.

The shales are not infolded Upper Cretaceous shales as reported by Spurr but, as will be shown later, are interbedded with the Comanchean limestones. They are commonly very much distorted and show the effect of squeezing. The shales are black when fresh but weather to a light yellowish-brown color.

A generalized columnar section of the Comanchean sedimentary rocks is shown in figure 3.

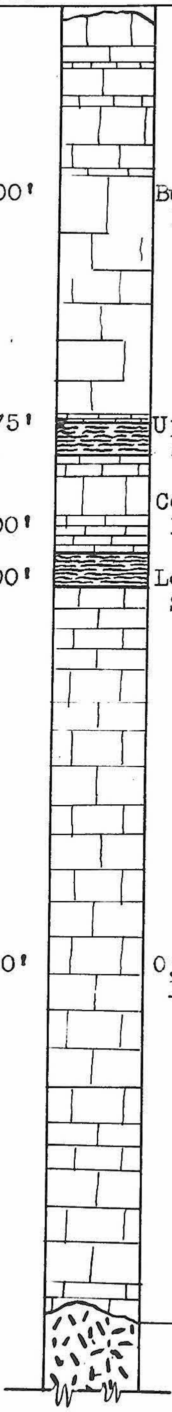
Ojuela Limestone

The Ojuela limestone, locally called the Lower Limestone, is the oldest formation exposed in the district. To the east, the limestone is overlapped by the detrital Quaternary deposits that fill the troughlike valleys of the region. It outcrops along the lower portion of the steep east face of the Sierra de La Bufa de Mapimi. The upper part of the formation is repeated several times by a series of faults and folds; typical exposures occur at the town of Ojuela. The thickness of the formation cannot be calculated as the lower part of the Ojuela limestone is not exposed in the district. Drill holes entered an intrusive rock at a depth of 3500 feet from the top of the formation.

The general strike of the Ojuela limestone within the area covered by the geologic map (Pl. 1) is N 35 degrees W, parallel to the major fracture systems.

The weathered rock has a dark gray color. The bedding is well defined and averages from 3 to 5 feet thick. Exceptional layers attain thicknesses of from 20 to 30 feet. Chemically, the limestone is slightly siliceous but otherwise very pure. The texture varies from medium to dense. The contact with the overlying shale formation is sharp and is in many places a plane of movement.

Figure 3. Generalized Columnar Section of the Rocks of the Mapimi District



Thickness	Name	Description	Age
±2000'	Bufa ls.	A series of thin-bedded highly fossiliferous ls. interbedded with massive layers. The thin-bedded portions are usually definite fossiliferous zones. The lower part of the formation is marked by a 1000' of unbedded, massive ls. with 4 thin layers at the base. Upper part of massive section weathers in cliffs and spires, and the lower portion weathers to boulder shapes.	WASHITA / FREDERICKSBURG — COMANCHEAN
±75'	Upper Shale	Black shale weathers light yellow. Extremely deformed. Secondary calcite seams and several calcareous layers. Forms benches or depressions parallel to strike.	FREDERICKSBURG — COMANCHEAN
±400'	Central ls.	Thin-bedded, gray ls. with one prominent 75' bed in middle of formation. Fossiliferous.	FREDERICKSBURG — COMANCHEAN
±100'	Lower Shale	Black shale, very similar to Upper Shale. Weathers yellow to brown. Usually forms benches parallel to the strike.	TRINITY — COMANCHEAN
±3500'	Ojuela ls.	Generally thin-bedded ls. Upper part fossiliferous. Color, dark to light gray. Weathers light gray. Two dolomite beds near top of section. Thickness unknown. Drill holes entered intrusive body 3500' below top of formation. Intrusion metamorphosed lower 200' of limestone, producing a coarsely crystalline white to light gray marble.	TRINITY — COMANCHEAN
		Acidic Intrusion.	

Several distinct fossiliferous horizons are present in the upper part of the formation, and the fauna is decidedly different from that found in the Los Lamentos limestone of the Santa Eulalia and Los Lamentos districts. However, the two limestones are equivalent in age.

The Ojuela limestone is the ore-bearing formation of the district. A number of favorable manto zones have been identified and will be described later. Intensely iron-stained areas occur near mineralized outcrops.

The sharp contact which separates the Los Lamentos formation from the underlying Black limestone in northern Chihuahua is not recognizable at Ojuela. It is probable that during the deposition of the two formations in the Mapimi district there was no abrupt change in sedimentation. Paleontological study of the Ojuela limestone of the Mapimi district may effect a subdivision. The fossils collected do not suffice to determine definitely the age of the formation. Tentatively it has been assigned to the Middle and Upper Trinity. The Ojuela limestone includes both the Black and Los Lamentos formations of the Santa Eulalia and Los Lamentos districts. The Los Lamentos apparently attained a greater thickness in the Mapimi district than in Chihuahua.

Two dolomite beds, 250 and 350 feet respectively below the top of the formation, weather white and serve as useful markers in the study of the structure, altho these beds are not so easily recognized underground as on the surface. However, several thin, pyritic, shale layers have been used underground to verify the structure as deduced from surface exposures.

Lower Shale

The Lower Shale conformably overlies the Ojuela limestone and averages 100 feet in thickness. It consists of laminated shales with occasional calcareous layers. During the regional deformation the shale was highly distorted. In many places originally thick beds have been so squeezed that they are now represented by thin, separated lenses. The shale is more susceptible to erosion than the limestones, and its presence is expressed topographically by benches or gullies parallel with its strike.

The shale is slightly pyritic, unfossiliferous, and indurated. Movement along the bedding planes is demonstrated by polished striated surfaces. Calcite veinlets cut the shale. The weathered rock has a characteristic dark yellowish-brown color. The fresh rock is dark-brown to black.

The Lower Shale has been tentatively correlated with the lower part of the Intermediate formation of northern Mexico and is equivalent to the lower Glen Rose of Texas.

The contact with the overlying Central limestone formation is transitional thru several layers of calcareous shale and shaly limestone. Over the surface of the district, long narrow bands of the Lower Shale separate the Ojuela from the Central limestone. The bands occur as conspicuous yellow zones that disappear under the Quaternary detrital deposits toward the north and south ends of the range.

Prescott[1] also regards this member as Lower Cretaceous in age. However, Spurr[2] considers the shale as an infolded Upper Cretaceous formation.

Central Limestone Formation

The Central limestone, as it is locally called, conformably overlies the Lower Shale. The transitional change from the shale to the limestone is rather abrupt, both chemically and physically. The Central limestone, in general, is a very pure, fairly compact, fossiliferous, dark-gray rock. It is well bedded. The average thickness of the beds is from 4 to 10 feet, but one prominent bed in the middle of the formation is 75 feet thick. Topographically the Central limestone appears as a rough precipitous slope or cliff. The average thickness of the formation is 400 feet.

The Central limestone is regarded as equivalent to the middle part of the Intermediate limestone of Chihuahua and the Glen Rose beds of Texas. The lower Rudistid beds of the Central limestone may be correlated with the Zone of Parahoplites, lowest zone of the Albian stage.[3]

The Central limestone outcropping along the eastern front of the range has been repeated several times by folding

1. Prescott, Basil, i.d. pp. 11-12.

2. Spurr, J. E., i.d. pp. 202-217.

3. Rose and Cavins, The Cretaceous and Tertiary of Southern Texas and Northern Mexico. Univ. of Texas Bull. No.2748.

and faulting. It is unimportant as a mineral-bearing horizon, altho sulphide veinlets cut the limestone at numerous points.

The contact with the overlying shale is sharp. Faulting has locally placed the Central limestone in contact with the Bufa which overlies the Upper Shale.

The Lower Shale, the Central limestone, and the overlying Upper Shale formation of the Mapimi district apparently are the equivalent of the Intermediate limestone of Chihuahua. Figure 4 shows a tentative correlation of the Mapimi section with those of northern Chihuahua.

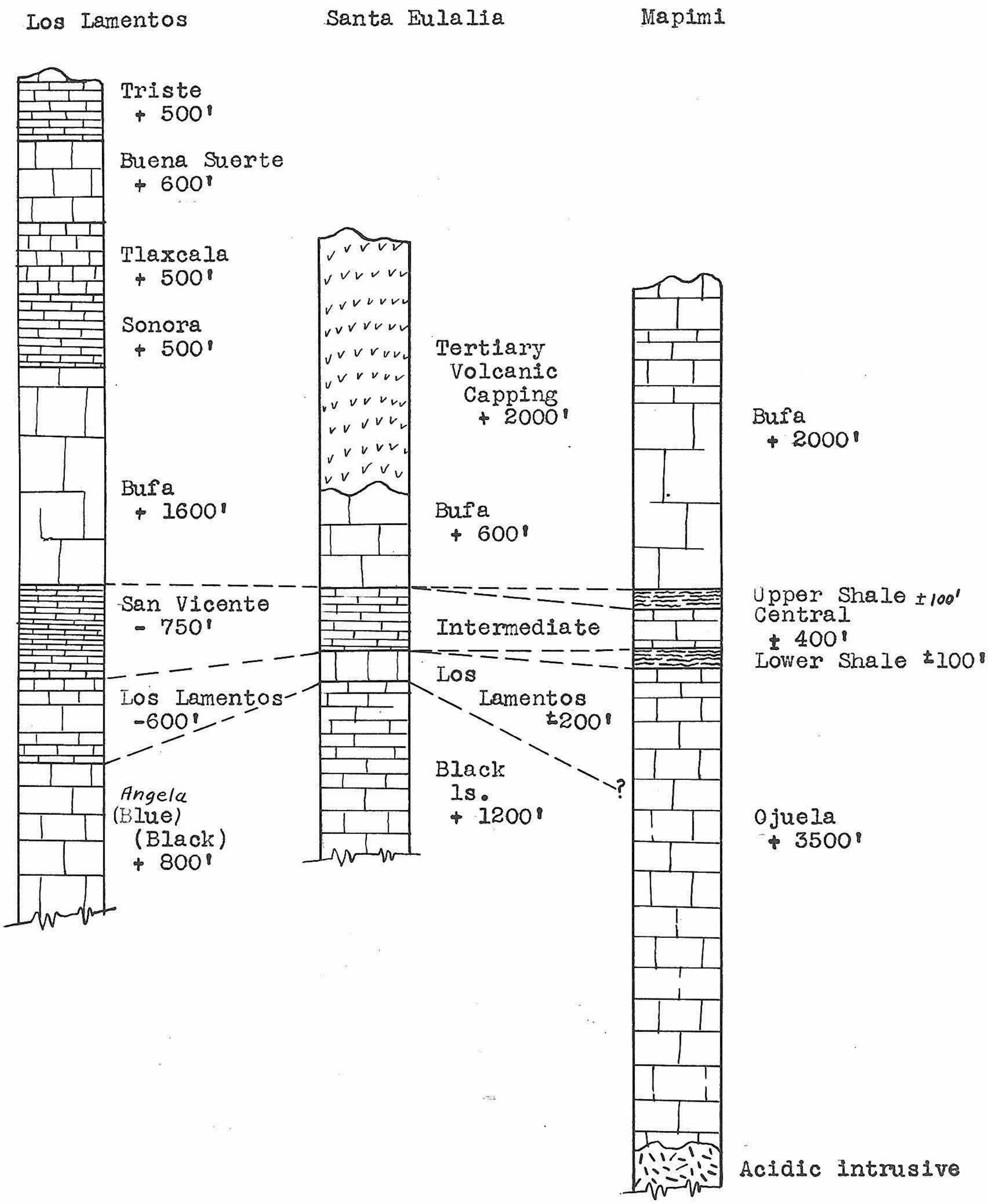
Upper Shale

The Upper Shale conformably overlies the Central limestone. The average thickness of the shale is 75 feet. It has a dark brown to black color when fresh but weathers to a light yellowish-brown, a color much lighter than that of the Lower Shale. It gives a fetid odor when struck with a hammer. Calcareous layers are rare.

Like the Lower Shale, the Upper Shale has been greatly deformed and has been subjected to intense squeezing. Secondary calcite films are common along the polished surfaces where slipping occurred during compression. The contact of the shale with both the Central and overlying Bufa limestones is generally a fault plane. Locally, faulting has brought the Central limestone into contact with the Bufa, and the Upper Shale is missing. The formation is unimportant as an ore-bearing zone.

Figure 4.

Columnar sections showing a tentative correlation of the sedimentary formations of the Mapimi district with Northern Chihuahua.



The position of the Upper Shale outcrop is easily recognized topographically. On account of its prevailing thin-bedded character, it forms a sharply contrasting slope between the bold cliffs of the underlying Central limestone and the still more imposing cliffs of the Bufa limestone.

The Upper Shale forms the top member of the Trinity Division of the Comanchean Series. It is apparently equivalent to the upper part of the Intermediate formation of Northern Mexico.

Bufa Limestone Formation

The Bufa, the youngest limestone of the Mapimi district, is the most prominent formation in the eastern part of the Mesa Central province. The lack of distinct bedding planes in the lower part, together with its compact texture, are responsible for the imposing cliffs on the east of the range.

The lower part of the Bufa limestone is definitely equivalent in age to the formation of the same name in Chihuahua. The upper part has not been positively correlated and it apparently includes a portion of the sedimentary rocks of the Washita division. It is, therefore, equivalent in age to the formations described by Ransome[1] above the Bufa in the Los Lamentos district. The entire sedimentary division above the Upper Shale in the Mapimi district is tentatively called the Bufa limestone.

1. The reader is referred to the paper on the Los Lamentos District (pp. 34-39).

The Bufa conformably overlies the Upper Shale with the contact marked by several thin beds of impure limestone. Above these, is a 1000 foot, massive cliff-making member. This division is by far the most conspicuous and extensively exposed stratigraphic unit in the range. The upper division is composed of several massive layers separated by thinner strata. It is fossiliferous and weathers buff to dark-gray. The massive beds have indistinct parting planes that can be traced for only short distances. The lower 300 feet of the Bufa weathers to rounded or boulder-shaped forms, and the upper 700 feet of the massive beds forms fluted cliffs or spires (fig. 5). The west versant of the range is approximately coincident with the dip of the Bufa beds.

Rudistids constitute a large portion of the fossil remains in the Bufa limestone and in certain beds are very abundant. The lowest Rudistid zone is a few feet above the base of the Bufa, and a second horizon occurs immediately above the lower 1000 foot massive division. The upper part of the Bufa is extremely fossiliferous and contains several horizons in which the remains are concentrated. The fossils are usually filled with coarsely crystalline calcite and do not separate from the matrix, altho they are very conspicuous on the weathered surfaces of the rock. The Rudistid specimens may be determined, however, from their diagnostic cross sections.

Figure 5. View looking up Socavon wash, showing the fluted cliffs of Bufa limestone in the background.

QUATERNARY WASH

The floor of the eastern part of the Mesa Central, as elsewhere in the arid southwest, is covered by unconsolidated to partially consolidated detrital deposits. The short ranges rising abruptly above the floor of the basins are flanked by this accumulation which is coarse and not readily distinguished from the stony debris upon the mountain slopes. The alluvial deposits from adjacent slopes fan outward and merge into the broad desert plains. The material deposited is fanglomeratic in character; and rock, characteristic of the parent range, may be identified several miles from its source. Farther out the material becomes finer, the particles more rounded, and the source less evident. The alluvial deposit attains great thickness in the region and as a rule is not deeply disected.

Accumulations of coarse detrital material occur in arroyos as shown by the geologic map. Such deposits are composed of large limestone boulders, and a small amount of clay derived from the shale and the whole partially cemented with calcium carbonate.

IGNEOUS ROCKS

Two types of igneous rock occur in the district. The first, a fairly acidic intrusive mass encountered below the mineral belt, is classified by Spurr as an alaskite. The rather abundant dark minerals in the rock and the predominance of plagioclase over orthoclase are not in accord with

Spurr's definition of alaskite. The rock has a vitreous to a pearly luster which suggests a great predominance of quartz. A petrographic examination shows that much of the apparently glassy material is albite.

Petrographic examination shows the rock to consist of the following primary minerals, listed in the order of abundance: albite, quartz, orthoclase, and subordinate amounts of hornblende and biotite. Titanite, magnetite, and apatite are the principal accessory minerals. The intrusive mass has a fine-grained granitic texture, and it may be classified as a granodiorite near soda granite.

The exact age of the intrusion is unknown. Definite zoning of the ore deposits above the intrusive mass leads to the conclusion that mineralization was directly related to the intrusion.

The limestone in contact with the intrusive rock has been intensely metamorphosed. The metamorphosed zone consists of a coarsely-crystalline white marble which grades upward into the unmetamorphosed limestone.

The second type of igneous rock is basic, definitely post-mineral in age, and is classified by Spurr[1] as diorite. It occurs as intrusive masses on the west side of the range, as numerous dikes cutting the sedimentary rocks, and as dikes cutting the ore bodies. The specimens examined were collected from dikes associated with the ore bodies. The

1. Spurr, J. E., 'Ore Magmas' 1923, Vol. 1. pp.202-214.

dike rocks are intensely altered in the vicinity of the ore bodies.

The altered specimens collected from dikes north of the ore deposits were formerly classified as hornblende-andesite porphyry.[1] A petrographic examination of four specimens, collected from dikes which cut the ore bodies, have the composition and texture of a diorite. Apparently all the post-mineral dikes were intruded contemporaneously and are diorites and diorite-porphyries.

Many of the dikes follow the pre-mineral faults of the northwest-southeast system. The post-mineral dikes at a number of localities are parallel to ore bodies, and in places large offshoots protrude into the ore.

1. Villarello, J. D., Le Mineral de Mapimi, Guide excurs. X Congr. Geol. Int. Mexico, 1906, XVIII, 18, p.2.

STRUCTURE

Broadly considered, the Sierra de la Bufa de Mapimi is a homocline of Comanchean sedimentary rocks, modified by folding and faulting, and later subjected to intrusion. It is a tilted block in which the beds, in general, dip in one direction at nearly the same angle. Such a homocline may conceivably represent either one limb of an anticline of which the crest has been eroded away, or a tilted fault-block. The Bufa is apparently a tilted, slightly arched fault-block that has later been deformed. The structure, however, is not as simple as it superficially appears.

Briefly, Spurr[1] believes that the limestones were upfolded by a deep seated dioritic intrusion, and that the folded sedimentaries were then buried by a thick deposition of Upper Cretaceous shale. Subsequently, continued erosion removed the greater part of the shale, leaving protuberances of the limestone. Further deformation, also supposed to be related with a hypothetical igneous intrusion, occurred during the erosion period. This deformation caused the doming of the range, and it was accompanied with sharp folding that enclosed layers of the Upper Cretaceous shale in the limestone. Faulting accompanied the folding. The exposed intrusive

1. Spurr, J. E., Ore Magmas, 1923, vol. 1, pp.202-214.

masses, according to Spurr, are "later emissaries of a buried dioritic column that caused the original doming of the range."

This investigation shows that faulting is an important factor governing the formation of the range and not a consequence, and that the shales, exposed along the east versant of the range, are not younger shales which have been infolded during later deformation, but which have a definite position in the Comanchean section.

The Mapimi range structurally resembles the Basin Range type. It is a tilted block with a north 30 to 40 degrees west strike. It is bounded, on the west for the greater part of its length, by a narrow shear zone and, on the east by a 6500 feet-wide zone of deformed and broken sediments. The block is tilted toward the west-southwest and that versant is approximately a dip slope. The open folded fault-block presents a steep escarpment to the east with a zone of intense deformation below the cliff face. Long troughlike depressions separate the range from the neighboring sierras to the northeast and southwest. The northwest front of the range is relatively straight, whereas the southeast side of the range is irregular. The modification of the southeast front is, in part, a result of a later intrusion.

The rocks, from the Ojuela limestone to the capping Bufa formation, outcrop at successive lower levels toward the northwest and southeast ends of the range as the result of a wide, transverse arch or anticlinal fold. A similar arch occurs in the Los Lamentos and Santa Eulalia ranges. The crest of the transverse structure is in the vicinity of Ojuela, and the best stratigraphic section of the range is exposed near the crest of the fold. In both directions, the range becomes progressively lower and narrower as the strata successively disappear beneath the floor of the Bolson de Mapimi.

The long, narrow vallgy east of the range is apparently a structural feature formed by faulting and not a synclinal basin, as described by Spurr.

The geologic map (Pl. 1) includes a part of the intensely deformed zone along the east front of the range. The zone is composed of a group of long, narrow bands of folded sediments that are bounded by high-angle reverse faults. A number of low-angle overthrust faults complicate the structure, and overfolding is very common.

The most intense deformation occurred in the western part of the zone, in which most of the ore bodies have also been found. The ore bodies as a whole differ in trend from the strike of the limestone and from the main system of faulting. The western boundary of the deformed zone is roughly marked by a contact of the Upper Shale with the Bufa. In some parts, however, the Central limestone has been faulted against the Bufa.

The Boulder fault, a steep upthrust, or high-angle reverse fault, with a strike of N 30-40 degrees W and a dip of

65-80 degrees W, is coincident with the general trend of the range. It forms the west boundary of the shear zone in the southern part of the area. It may be due to a northern contimuation of this fault that the Central limestone is in contact with the Bufa limestone west of the Talpa shaft.

A number of strong faults lie east of the Boulder fault and like it, are mostly high-angle reverse faults which dip to the west. The most important are the Providence, Central, San Vicente, Bridge, Agua Verde (?), Cambia, San Juan, Carmen, Cabriza, Cumbres, and Santa Elena. The strong San Diego and possibly the Agua Verde belong to a second system of faults which are apparently pre-mineral in age, altho they have undergone pronounced post-mineral movement.

The Central fault is one of the most persistent in the district. It can be traced both north and south of the area mapped. It generally marks the contact of the Central limestone with the Lower Shale. The long, narrow strip between the Central fault and the Bufa limestone to the west, is composed of sharply folded Central limestone and Upper Shale. Reverse faulting accompanied the folding in the southern part of the zone. The intense deformation squeezed the shale into separated, lenticular bodies. The width of the zone increases from 400 meters in the south to 650 meters in the north.

Between the Central and the San Vicente Fault to the east is a second well-marked strip with a general northwest-southeast strike. The Lower Shale and the Ojuela limestone have been compressed into a sharp anticlinal fold with the San Vicente Fault, showing considerable displacement, breaking the anticline along or near its crest. The San Vicente is a high-angle reverse fault. It dips 70-85 degrees west and is commonly vertical in the southern part of the district.

The southern part of the strip, bounded by the Central and San Vicente faults, is a rather simple fold, while in the north, several faults parallel to the San Vicente modify the structure.

The third, narrow, wedge-shaped strip is bounded by the San Vicente fault on the west and the Cambia fault on the east. This area, so bounded, has a much greater width than the previously described blocks and has also the most complicated structure found in the district. The southern part of the wedge is broken by several important pre-mineral faults which are parallel to the San Vicente. The faults have the greatest displacement near the crest of the transverse arch in the vicinity of Ojuela. The displacement rapidly diminishes to the north. The Cambia fault divides just south of the town of Ojuela. One component, the Cambia, continues north with a N 20 degrees W strike, and the other branch, the San Juan, has a N 40 degrees W strike.

The strong San Diego fault cuts diagonally across the block with a general strike of N-S to N 5 degrees W. It is apparently a pre-mineral fault with some post-mineral activity. The Agua Verde belongs to the same system as the San Diego and has also been a plane of post-mineral movement.

Several important overthrust faults are shown in the geologic sections (fig's. 6, 7, 8).

The ore bodies are related to the pre-mineral faults and folds and, with some important exceptions, are confined to the wedge-shaped block just described.

The zone east of the Cambia extends under the aluvium of the valley. To the south, the zone is, in general, an anticline, the Cumbres Anticline. The form of the fold has been complicated by overthrusting along the Cumbres fault. Northward, the Cumbres anticline passes into a syncline. East of this syncline lies another anticline which is similar to the Cumbres Anticline.

The chief features of the structure of the Mapimi district are summarized as follows:

1. The Sierra de la Bufa de Mapimi is apparently of fault-block origin. Zones of weakness occur at the base of the range on the west and east sides.
2. The compressional stress responsible for the folding, which is a comparatively simple homoclinal structure modified by several open transverse folds, was probably exerted from the southwest.
3. In the zone of deformation, along the east base of the range, faulting is the most pronounced structural feature.
4. The shale layers in this vigorously deformed belt have definite positions in the Lower Comanchean series.

5. The mineralization apparently is genetically related to an intrusion of a siliceous magma which possibly solidified as a small batholith or stock, with its major axis striking more nearly north than the trend of the range.

6. The dioritic intrusions are post-mineral in age.

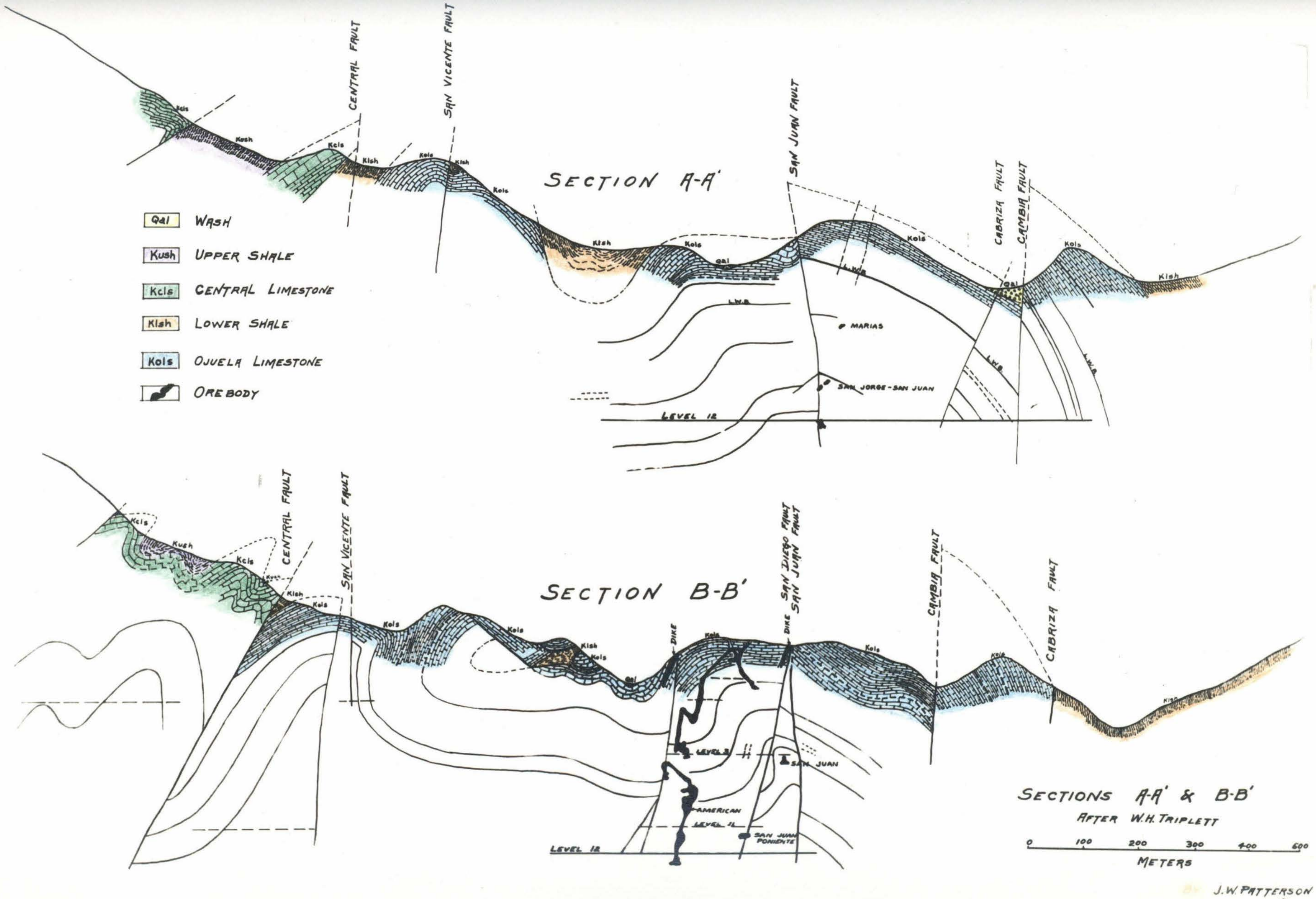
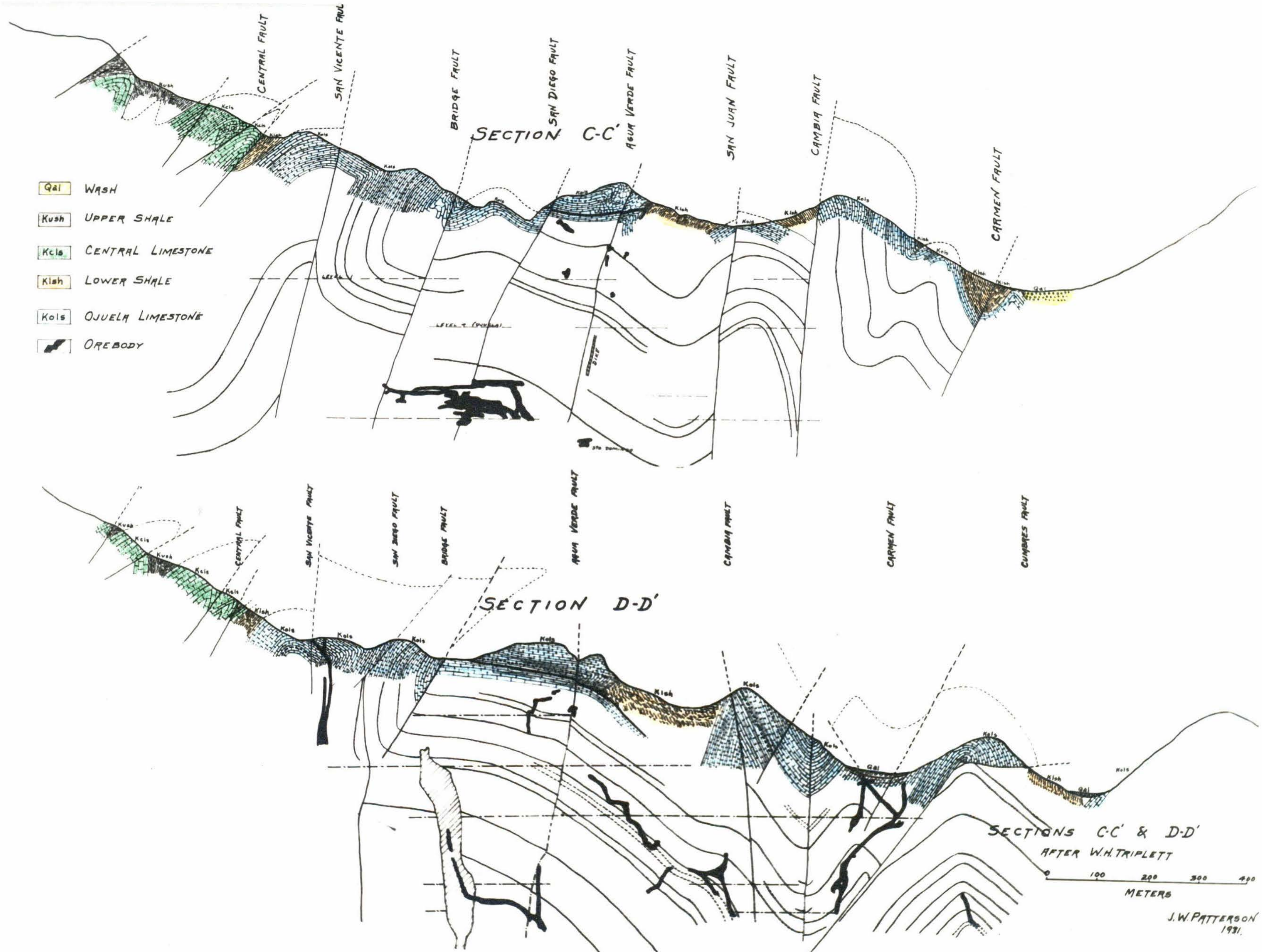

SECTION A-A'
SECTION B-B'
Qal WASH
Kush UPPER SHALE
Kcls CENTRAL LIMESTONE
Klsh LOWER SHALE
Kols OJUELA LIMESTONE
OREBODY
CENTRAL FAULT
SAN VICENTE FAULT
SAN JUAN FAULT
CABRIZA FAULT
CAMBIA FAULT
SAN DIEGO FAULT
DIKE
MARIAS
SAN JORGE-SAN JUAN
LEVEL 12
LEVEL 3
SAN JUAN
AMERICAN
SAN JUAN PONIENTE
SECTIONS A-A' & B-B'
AFTER W.H. TRIPLETT
0 100 200 300 400 600
METERS
J.W. PATTERSON
1931

Figure 6.



Qal WASH
Kush UPPER SHALE
Kcls CENTRAL LIMESTONE
Klsh LOWER SHALE
Kols OJUELA LIMESTONE
OREBODY
SECTION C-C'
CENTRAL FAULT
SAN VICENTE FAULT
BRIDGE FAULT
SAN DIEGO FAULT
AGUA VERDE FAULT
SAN JUAN FAULT
CAMBIA FAULT
CARMEN FAULT
SECTION D-D'
CUMBRES FAULT
SECTIONS C-C' & D-D'
AFTER W.H. TRIPLETT
0 100 200 300 400
METERS
J.W. PATTERSON
1931.

Figure 7.

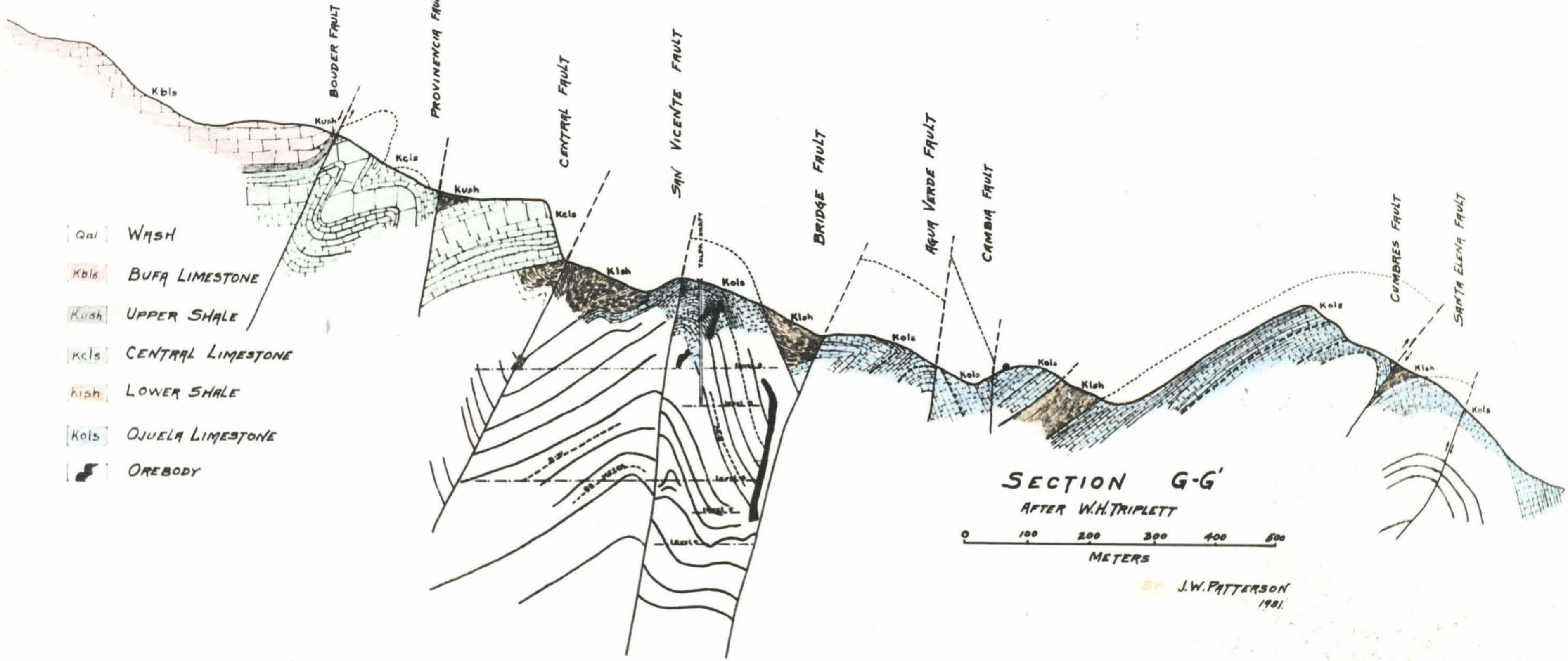

BOUDER FAULT
PROVINENCIA FAULT
CENTRAL FAULT
SAN VICENTE FAULT
BRIDGE FAULT
AGUA VERDE FAULT
CAMBIA FAULT
CUMBRES FAULT
SANTA ELENA FAULT
Kbls
Kush
Kcls
Klsh
Kols
Qal WASH
Kbls BUFA LIMESTONE
Kush UPPER SHALE
Kcls CENTRAL LIMESTONE
Klsh LOWER SHALE
Kols OJUELA LIMESTONE
OREBODY
SECTION G-G'
AFTER W.H. TRIPLETT
0 100 200 300 400 500
METERS
J.W. PATTERSON
1981.

Figure 9.

MARKER BEDS

Particular layers are utilized to interpret the structure underground in the Santa Eulalia district.[1] The work led to the association of known manto deposits with limited stratigraphic zones in that district. W. H. Triplett of the Penoles Company introduced the method into the Mapimi district and has attained equally good results. The markers are designated by numbers; the number assigned to each marker indicates the depth in meters of the upper surface of that particular bed below the base of the Lower Shale formation. The structure interpreted in the mine by the use of the marker beds confirms the results obtained by surface work. The cross sections are shown in figures 6, 7, 8, 9.

The first two markers known as the 75 and 115 meter beds are dolomitic layers, respectively 1.4 and 1.5 meters thick. They weather light-gray and stand out boldly in contrast to the darker limestone. These dolomite beds were used extensively in mapping on the surface, whereas underground they are not easily recognized and are, therefore, inadequate as guides.

The 151 and 160 beds are used extensively in the mine. The 151 marker consists of three 25 cm. layers, bounded by

1. The reader is referred to the paper on the Santa Eulalia District for a description of the marker beds.

sharp bedding planes. These three layers are from 1.5 to 2 meters apart with the upper bed 151 meters below the shale contact. The 160 marker occurs below the 25 cm. bands. The 3 beds may be used to distinguish the 160 from the very similar 230 marker. The 160 marker is characterized by 3 meters of very dark limestone. This limestone contains large, white, imperfect shells of lamellibranchs. It is underlain by a 15 cm. layer of hard, shaly, pyritic limestone which is cut by veinlets of calcite. In the vicinity of the ore bodies, the pyritic bed alters to a red or yellow clay, very similar to a fault gouge.

The 170 marker is a definite bedding plane below a very dark gray limestone. A light gray bed, containing small fossils filled with a white coarsely crystalline calcite, is immediately below the prominent bedding plane.

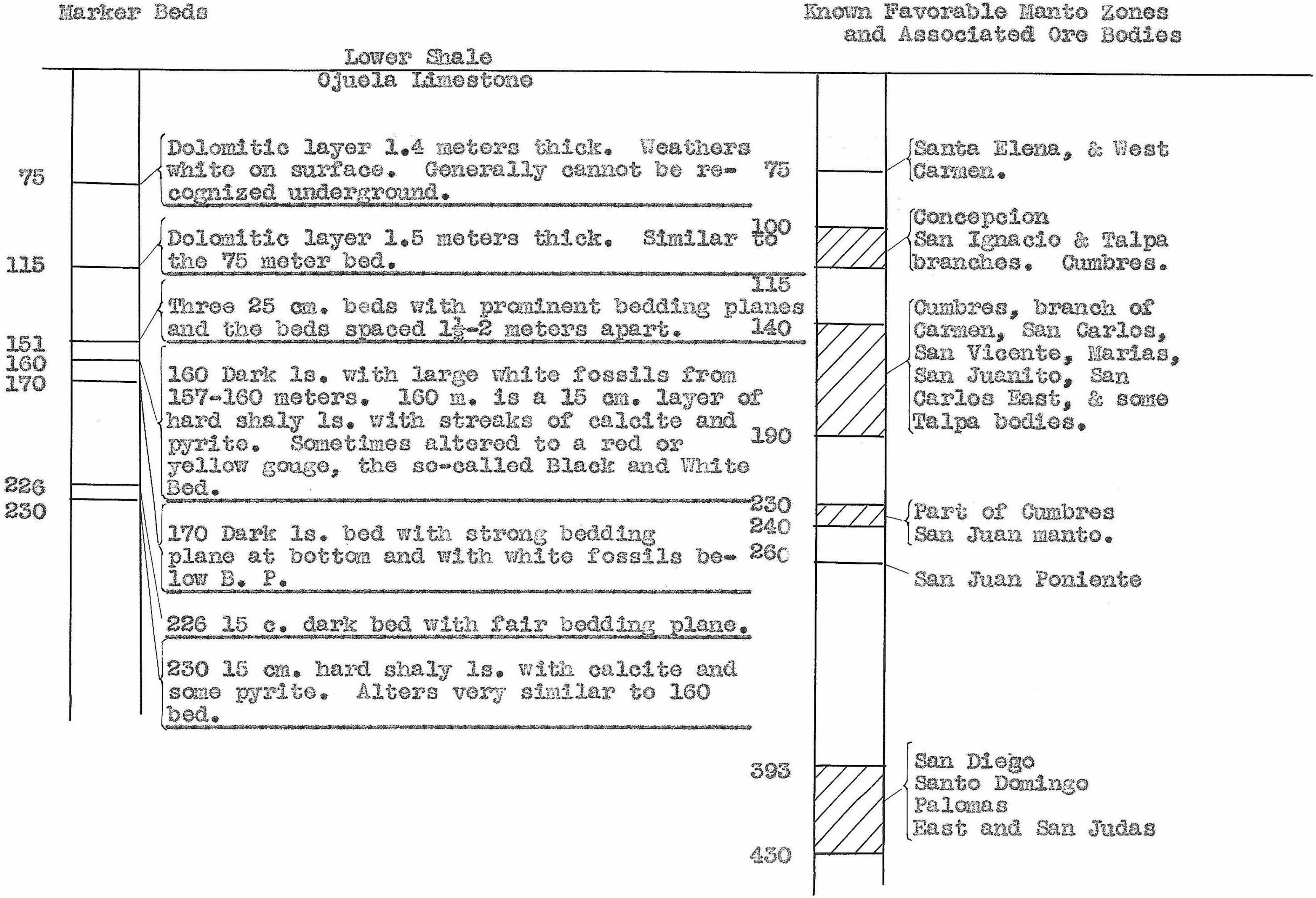
The 226 marker is a 15 cm. band of very dark limestone, bounded by distinct bedding planes. The 230 marker which is similar to the 160 bed is 4 meters below.

Undoubtedly, other markers will be identified and utilized to map the underground structure in greater detail.

MANTO HORIZONS

Ore bodies having a manto form, that is, long narrow or ribbon-like deposits which follow the bedding of the inclosing rocks, are confined to certain stratigraphic zones. Stratigraphic correlation of the known ore bodies in the

Figure 10


Marker Beds
Lower Shale
Ojuela Limestone
Known Favorable Manto Zones and Associated Ore Bodies
75
115
151
160
170
226
230
Dolomitic layer 1.4 meters thick. Weathers white on surface. Generally cannot be recognized underground.
Dolomitic layer 1.5 meters thick. Similar to the 75 meter bed.
Three 25 cm. beds with prominent bedding planes and the beds spaced 1½-2 meters apart.
160 Dark ls. with large white fossils from 157-160 meters. 160 m. is a 15 cm. layer of hard shaly ls. with streaks of calcite and pyrite. Sometimes altered to a red or yellow gouge, the so-called Black and White Bed.
170 Dark ls. bed with strong bedding plane at bottom and with white fossils below B. P.
226 15 c. dark bed with fair bedding plane.
230 15 cm. hard shaly ls. with calcite and some pyrite. Alters very similar to 160 bed.
75
100 to 115
140
190
230
240
260
393
430
Santa Elena, & West Carmen.
Concepcion
San Ignacio & Talpa branches. Cumbres.
Cumbres, branch of Carmen, San Carlos, San Vicente, Marias, San Juanito, San Carlos East, & some Talpa bodies.
Part of Cumbres
San Juan manto.
San Juan Poniente
San Diego
Santo Domingo
Palomas
East and San Judas

Mapimi district shows a number of zones which are especially favorable sites for manto deposits. Fortunately, a number of the recognizable marker beds are coincident with some part of a manto horizon. Favorable manto sites and marker beds, with a list of known manto ore bodies, are shown in tabular form as fig. 10.

The two dolomitic beds, markers 75 and 115, are notable examples of markers that are also favorable manto horizons. They are the only dolomite beds associated with the deposits. The Santa Elena and West Carmen have a manto form in the 75 marker. Within the favorable 15 meter section, between the 100 meter bed and the 115 marker, the Concepcion, San Ignacio, part of the Talpa, and a branch of the Cumbres have strong manto sections.

The most favorable manto zone in the district is the horizon limited by the 140 and 190 beds. The 190 meter bed, almost without exception, marks a stratigraphic horizon where ore bodies change from the chimney to the manto form. The mantos usually rise gradually by successive short steps to the upper beds of the zone and extend to the surface, or to some strong pre-mineral fault. The ore body may again assume the chimney form at such a fault and follow the fault to the surface or to a higher manto horizon. The Incline, San Vicente, Marias, San Juanito or San Carlos East, the Cumbres, and several of the Talpa mantos are within the 140-190 zone.

A part of the Cumbres deposits have a manto form at the 230 horizon, while the San Juan manto has followed the 240 marker. The San Juan Poniente manto follows the 260 marker.

The deepest known manto zone is bounded by the 393 and 430 meter beds. In this zone, the San Diego, Santo Domingo, Palomas-Ojuela, East, and San Judas ore bodies have strong mantos. Similar to the 140-190 meter zone, the mantos gradually rise from the lower part of the zone to the higher beds.

By a correlation of the stratigraphic position of known mantos in a district, it is possible to predict the probable occurrence of mantos in certain places and to avoid extensive exploration of ground that is probably barren.

ORE DEPOSITS

The major replacement deposits of the Mapimi district are confined to the Ojuela limestone in an intensely folded and faulted zone along the northeast slope of the Sierra de la Bufa de Mapimi. The deposits, in general, may be classified according to form into chimneys and mantos.[1] They are very irregular and form a complicated system.

The ore bodies have a tendency to combine at depth to form large, regular shaped chimneys; a character well demonstrated by the Santa Eulalia deposits. At Ojuela, it is quite evident that the ore-bearing solutions emanated simultaneously from several points; while at Santa Eulalia, the ore bodies extend upward and outward from one large chimney, the site of which was apparently the channel for the ore-bearing solutions.

An ore body, from its lowest chimney to the surface, may consist of several mantos connected by chimneys. The part of the deposit having a chimney form connects with mantos in the favorable manto zones, altho exceptions occur when the chimneys are associated with pronounced zones of intersecting fissures.

Individual ore bodies have a trend of N 30-40 degrees W, parallel to the major faults and folds. The mineralized zone

1. The reader is referred to the paper on the Santa Eulalia district, pp. 63, 64.

has a N 20 degrees W strike; a strike that is coincident with the alignment of the chimneys in the lower part of the mine. It probably coincides with the strike of the axis of some buried structure, or possibly with the axis of an intrusion that was apparently the source of the ore-bearing solutions.

A pronounced increase in the cross section of an ore body near the water table marks the change from the massive sulphides to the porous oxide deposits. Aside from the above exception, the cross section of an ore body gradually diminishes away from the source.

The deposits show a pronounced change in the character of the ores within their known vertical range. Ore bodies, equidistant from a common chimney or from different chimneys, may contain ores that have different compositions. The differences between ores of apparently related deposits diminishes with depth. Assays together with position and attitude of certain deposits are indicative of the places of probable union.

Several ore bodies, selected from the large number of deposits of the district, will be briefly described in order to illustrate their form, habit, and relation to structure.

Cumbres Ore Body

The Cumbres ore body is essentially a group of intricately related mantos and chimneys that, in general, ascend toward the southeast and follow along or near the crest of the Cumbres

Anticline.[1]

Below the 12th level (water level), the Cumbres deposit consists of a group of inclined chimneys. From the 12th to the 4th levels, it is composed of a complicated series of mantos which follow the bedding along the crest of the northern limb of the Cumbres Anticline. The mantos are associated with the favorable beds of the 140-190 meter manto zone. The chimney deposits assume a manto form at the 190 meter marker and follow the bedding toward the south. They step upward from lower to successively higher strata within the favorable manto zone. This rising to a higher stratigraphic position continues until the 140 meter bed is reached. The mantos then extend south associated with the 140 marker.

A pre-mineral fault traverses the deposit near the 4th level. Its strike is at a small angle to the axis of the anticline. The form of the deposit changes at the fault; one part of the deposit crosses it and continues south as a manto; the remainder, a chimney, is guided upward by the fault. A manto extends south from this chimney at the 115 meter marker, and the chimney, much reduced in cross section, rises to the contact of the limestone and shale. Apparently the pre-mineral fault zone which was crossed by part of the ore body was not as susceptible to deposition and replacement as the broken limestone along the crest of the anticline.

1. Prescott, Basil, The underlying principles of the limestone replacement deposits of the Mexican Province, E & M J., vol. 122, no. 8, Aug. 21, 1926.

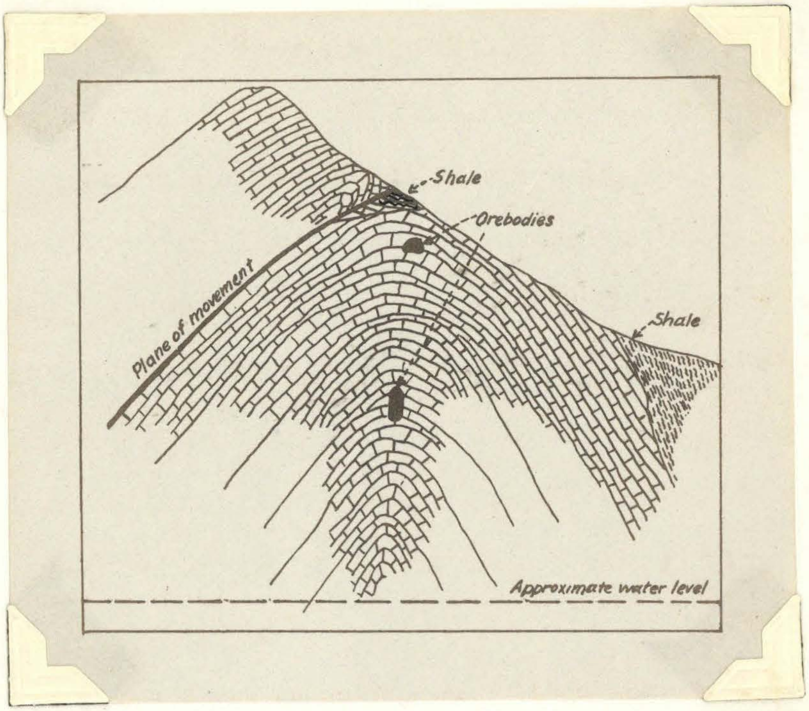


Figure 11. Cumbres Ore body.

Section thru line A-A' of Pl. IV. (After Prescott.) By permission Cia. Minera de Penoles, S.A.

The segment of the ore body extending south of the fault, is associated with the 140 marker (plate iv), and it joins another chimney in a fractured zone and rises to the 75 meter horizon where it assumes a manto form, and, with a diminishing cross section, extends 500 meters south. This upper manto is known as the Santa Elena ore body.

Another manto within the 230 meter manto zone (plate iv) probably joins the Cumbres Chimney.

A longitudinal section of the Cumbres ore body is illustrated and the markers are plotted (plate iv). Transverse sections of the Cumbres ore body are shown on figures 8, 9, & 11.

San Carlos Ore Body

The lower part of the San Carlos ore body is a chimney associated with a pronounced pre-mineral fault. The chimney extends along the fault, and its form is very similar to a shoot in a vein. It is quite different from the normal form of a chimney and is illustrative of the influence exerted by a pre-mineral fault during mineralization.

Near the water table, the chimney reaches the lower limit of the favorable 190-140 meter zone. The deposit then assumes a manto form and follows the bedding to the surface. The rocks are folded into a sharp anticlinal fold and have a dip of 40 to 50 degrees. Replacement extended farther laterally than is characteristic of mantos in general, and the deposit is thin compared to its width. The relatively steep dip of the beds was apparently responsible for the spreading of the ore. This manto is similar in form to that of a blanket deposit.

The plan and a section of the San Carlos ore body are shown in figure 12.

Carmen Ore Body

The Carmen ore body is, in part, analogous to the San Carlos, that is, it ascends to the surface along the bedding of the limb of a steep anticline. At one point, however, the deposit leaves the basal beds of the 190-140 meter manto zone and rises in chimney form to the upper part of the horizon where it again follows the bedding. The gradual stepping from one bed to a higher stratum within the manto zone as shown by the Cumbres mantos, does not occur in either the San Carlos or Carmen ore bodies. The Carmen manto is similar to the San Carlos; it is thin but much wider than is usual for the manto deposits.

San Juan-San Jorge Ore Bodies

The lower part of the San Juan-San Jorge ore body is a chimney which is associated with a pre-mineral fault and extends 200 meters above the water table. The fault shows a displacement of approximately 100 meters. At several places dioritic dikes fill the fault. About 200 meters above the water table, the chimney connects with a manto associated with the favorable zone which is bounded by the 240 and 230 markers.

The manto deposit follows the bedding south along the crest of a broken anticline for a distance of 500 meters. The manto parallels the pre-mineral fault that is associated with the chimney but is not coincident with it. The manto, at its southern end, crosses the fault, and then the deposit, in the form of a chimney, rises to the surface. The projection (fig. 12) shows the longitudinal and transverse sections of the ore body.

San Judas-Santa Rita Ore Bodies

The lower extensions of the San Judas-Santa Rita ore bodies are a group of related chimneys. The chimneys join a group of mantos that continue to the southeast. The mantos are associated with the favorable beds of the 430-393 meter manto zone. The southern ends of the mantos connect with a group of chimneys that rise from the 7th level to the surface. The chimneys follow a pre-mineral fault. The influence of the fault on the shape of the deposits is shown by the vein-like form of the chimneys, instead of the normal elliptical shape. Below the manto horizon the fault was unimportant as a locus for ore bodies. A composite plan and a section of the San Judas-Santa Rita ore bodies are shown on Plates II & III.

San Diego Ore Body

The lower San Diego ore body is a manto associated with

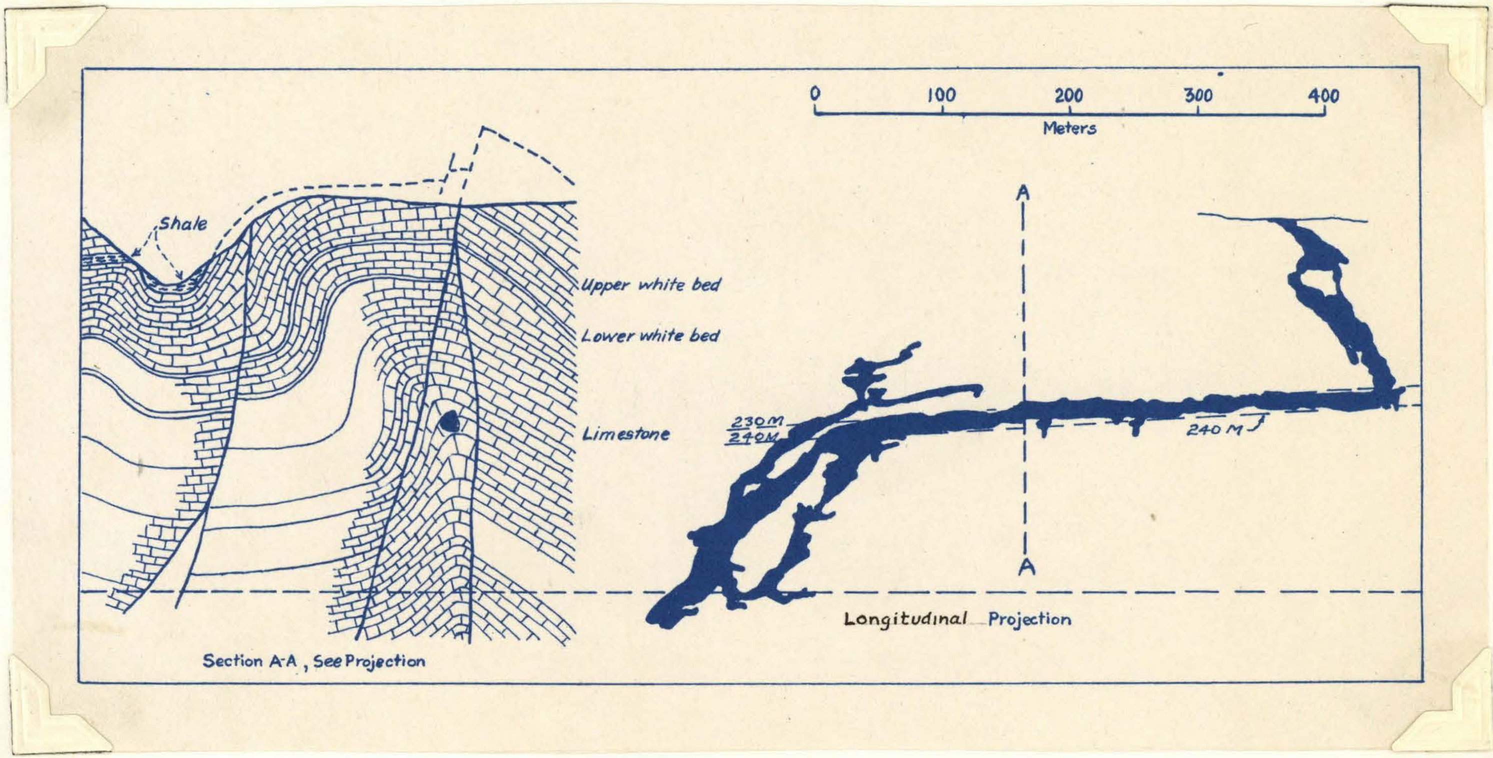


Figure 12. San Jorge-San Juan Ore body. By permission Cia. Minera de Penoles, S.A. (modified after Prescott.)

the lowest beds of the 430-393 meter manto zone. The ore body crosses the strong San Diego fault, (pre-mineral ?), and 100 meters south of it, rises as a chimney to the upper favorable layers of the manto horizon where it again extends south following the bedding. This upper manto follows the distorted structure, a huge 'Z' shaped fold, until the San Vicente fault is reached. The deposits then, as a group of chimneys guided by the San Vicente fault, extend to the surface.

Ojuela-Palomas Ore Bodies

The Ojuela-Palomas ore bodies have been mined from the surface to a depth of 3000 feet. The Ojuela was the first ore body to be worked and, at present, is one of the largest producers in the district.

The lowest deposits are a series of large related chimneys. A number of mantos extend from the chimneys in the favorable manto horizons below the water table, while above the water table, a group of large mantos occur within the 430-393 meter manto zone. Several chimneys extend upward from the mantos. As the succeeding favorable zones are crossed, mantos extend outward from the chimneys, and the chimneys, reduced in cross section contimue to the surface.

Stopes or mined-out chimneys indicate the size of the original deposits. They attain diameters up to 50 meters and heights up to 300 meters. The belief that the ore bodies were deposited without definite control by fissures or beds, as has been suggested,[1] is purely an assumption that is very doubtful.

The Ojuela-Palomas chimney segments below the water level are very regular in shape and will probably unite to form a larger chimney deposits.

The position, form, and mineral character of the deposits in the district suggests that several other ore bodies unite to form larger deposits at a greater depth. The ore bodies which will most probably unite to form larger deposits are as follows:

1. The two branches of the Cumbres ore body may combine to form a large, regular chimney within 100 meters of the bottom of the present workings.
2. The San Juan-San Jorge ore body and the San Juan Poniente show indications of combining at a depth within 400 meters of the water table.
3. The American ore body will probably unite with the San Diego and the Santo Domingo ore bodies.
4. The San Judas-Santa Rita and the Tesoro ore bodies may combine to form another large chimney.

The majority of the known lower chimneys lie along two N 20 degrees W lines and thus bear no relation to the structure of the range. The San Diego fault, a probable pre-mineral

1. Prescott, Basil, i.d. p. 12.

fracture with post-mineral movement, is the only important structural feature that has a trend that is coincident with the alignment of the deeper chimneys. This alignment of chimneys strongly suggests that some buried structure or intrusive body had a pronounced influence upon the location of the deeper deposits. The writer believes that the alignment of the lower chimney deposits and the general trend of the mineralized zone is coincident with the strike of the longer axis of an intrusive body, rather than a buried structure, altho a definite conclusion from the available evidence is not possible.

Most of the ore deposits in the upper part of the mines are definitely associated with some geologic feature such as, a pre-mineral fault, limb of a fold, crest of an anticline, and occasionally the trough of a syncline. The association of the lowermost deposits with the known geologic features is less pronounced, and the deposits occur at any point of the structural features or crosses them.

ORE AND GANGUE MINERALS

A list of identified ore and gangue minerals is given below. Altho not complete, it probably contains a sufficient number ofminerals to describe the deposits. The mineral association is common to lead-zinc-silver replacement deposits. There is a noteworthy absence of the rare heavy iron silicate minerals, fayalite, ilvaite, and knebelite found in the Santa Eulalia district. However, a number of lime-rich silicates are found in the Ojuela deposits.

List of Minerals

Gold
Silver
Sulphur
Sphalerite
Pyrite
Chalcopyrite
Galena
Arsenopyrite
Boulangerite
Stibnite
Proustite
Pyrargarite
Cerargarite
Fluorite
Quartz
Hematite
Magnetite
Limonite
Psilomelane
Pyrolusite
Anglesite
Cerussite
Calcite
Dolomite
Gypsum
Barite
Bindheimite
Dussertite
Arseniosiderite
Scorodite
Carminite
Jarosite
Plumbojarosite
Wulfenite
Mimetite
Pyromorphite
Malachite
Azurite
Hydrozincite
Calamine
Rhodocrosite
Diopside
Wollastonite (?)
Hedenbergite
Tremolite
Serpentine
Chlorite
Uralite

The hypogene ore minerals, except pyrite and magnetite, were deposited at a moderate (mesothermal) temperature and depth. Magnetite is a mineral which is usually associated with the higher temperature (pyrometasomatic and hypothermal) deposits; and pyrite is a mineral which is recognized as having been deposited thru a great range of temperature.

Several of the hypogene gangue minerals are indicative of a higher depositional temperature than the mesothermal ore minerals. The silicates are common in the lower deposits of the mine and will probably become even more abundant at greater depth.

Classification of the Ores

The ores may be divided into three classes, each coincident with a zone. Two groups of the ores are found in a primary state, while the third has been almost completely oxidized.

Classification of the ores is based primarily upon the preponderance of the different original component sulphides. The primary ores are usually of comparatively simple mineral composition. They contain a few common minerals in relatively large amounts together with small, though important, quantities of less common minerals. They are predominantly mixtures of pyrite, sphalerite, galena, and arsenopyrite, and locally, chalcopyrite. The component minerals of the sulphide ores are mingled in very different proportions. The diagram, figure 13, shows the relative period of formation of the principal ore minerals.

The ores which contain more than one sulphide mineral in large amounts are called 'massive sulphides' or 'mixed sulphide ores'. The latter term is preferable.

The ores of the Mapimi district are grouped as follows:

I. Zinc- arsenic - lead - copper ores.

II. Lead - zinc ores.

III. Silver - lead ores.

Group I.

Group I, the zinc-arsenic-lead-copper ores, occur in the deepest workings of the mine. The massive sulphide ores consist of arsenopyrite, chalcopyrite, galena, pyrite, and sphalerite with a lime silicate, quartz, fluorite, barite, and calcite gangue. The sulphides occur as coarsely crystalline, massive replacement bodies with a very small amount of associated gangue material. The ores have been considerably enriched with hypogene silver minerals. Garnet, quartz, and fluorite, in addition to being mixed with the massive sulphide ores, occur as veinlets cutting the sulphides.

Blende is the most abundant sulphide in the group and is followed in order of abundance by pyrite, galena, arsenopyrite, and chalcopyrite. Large masses of arsenopyrite occasionally segregate within an ore body or form a shell enclosing the deposit. Arsenopyrite is abundant in the Lower San Diego ore body. The chalcopyrite and arsenopyrite in the mixed sulphide ores are very erratic in distribution.

There are three varieties of texture and structure of the ores, and they offer features of unusual interest. The first, a massive structure, is shown in the semi-porous granular aggregates of the different sulphides in the larger chimneys and lower mantos. The massive ores show no special regularity in the relative size and distribution of the grains.

Occasionally a vuggy structure occurs within the massive deposits. The small vugs are usually lined with quartz or carbonates. The cavities may be so numerous that the ore becomes a porous aggregate of nearly complete sulphide crystals. This type of ore disintegrates easily.

The third type, a banded structure, is most prominent in the mantos composed of both Group I and II ores. One type of banding is parallel to the bedding. The second type of banding which is by far the most important is related to the fracturing. The favorable manto zones were very susceptible to fracturing and this produced a well broken zone bounded by strata which the fracturing was less pronounced. The ore-bearing solutions then ascended within the fractured limestone and the replacement produced a banded deposit in which the layers are parallel to the fractures. The replacement was toward the center of individual blocks simultaneously from all sides. The shape and size of the limestone blocks are clearly marked even ina deposit where replacement has been complete. Occasionally unreplaced limestone is found surrounded by banded sulphides. The banding of the 'mixed sulphide ores' does not show any pronounced separation of minerals as might be expected.

Group II

The ores of Group II, lead-zinc ores, aside from the ratio of the metallic constituents to each other, are similar to those of the first group. They are mixed sulphide ores and consist of galena and pyrite with subordinate amounts of arsenopyrite. sphalerite, and boulangerite. The gangue minerals form but a small part of the ore, and it consists chiefly of quartz, barite, fluorite, calcite, and magnetite. Silicates are less abundant than in the ores of Group I, and are rare in the upper most sulphide deposits.

Galena is the most abundant sulphide, and it is followed in order of abundance by pyrite, arsenopyrite, sphalerite, boulangerite, and chalcopyrite. Deposits of this class of ore have been found over a vertical range of 800 feet. The major hypogene deposits of the district consist of ores of this group. The ores of the upper deposits of Group II approach the composition of the ores of Group III; and the lower deposits approach the composition of those of Group I.

Several mantos, one of the upper Palomas mantos, for example, contain deposits in which the gangue is exceptionally abundant and consists chiefly of fluorite, barite, quartz, and carbonate.

Large masses or segregations of galena surrounded by 'mixed sulphides' are common, especially in the chimneys. Some of the galena masses are 5 meters in diameter and 25 meters in length. The structure and texture of the ores of this group are identical with those of the Group I ores.

Group III

The ores of Group III, silver-lead ores, are almost totally oxidized. The occasional sulphide remnants indicates that the ores consisted chiefly of galena, pyrite, arsenopyrite, and sphalerite, with subordinate quantities of sulpharsenates and sulphantimonates of lead and silver. The gangue is chiefly quartz, carbonate, fluorite, and barite.

The oxidized ore consists of a remarkable group of lead, iron, silver, zinc, arsenic, and gangue minerals. The most common oxidized ore minerals are cerargyrite, cerussite, anglesite, hematite, limonite, jarosite, and plumbojarosite. Quartz, gypsum, calcite, barite, and fluorite are the common gangue minerals.

The ores are generally bedded similar to those of the Los Lamentos and Santa Eulalia districts.[1] The bedding is indicative of the migration of the metallic constituents during oxidation. The inclined mantos of Ojuela are generally much wider than those of Los Lamentos and Santa Eulalis, and

1. The reader will find detailed descriptions of oxidized mantos in the papers on the Los Lamentos and Santa Eulalia districts.

the wide deposits are relatively thin. The open spaces above the ore are likewise very wide and low at Ojuela.

Oxidized ores, altho for a long time the principal source of the metals, have for some years been contributing less than the sulphide ores to the output of the district. The major production of oxidized material at present is obtained by the re-working of old stopes, and the new bodies that are occasionally found.

The oxidized material is a soft, friable, earthy-mixture. The ore is roughly bedded and occasionally surrounds unreplaced 'boulders' of limestone or blocks which fell from the roof during oxidization.

Oxidation extended to over 50 meters below the present water level.

Zonal Distribution of the Ores

The ore deposits show a progressive change in composition from argentiferous galena ores containing considerable chalcopyrite, arsenopyrite, and sphalerite to those in which these minerals are rare. This change in composition, altho the demarcation is not conspicuous, distinguishes the three described groups of ores. The occurrence of the ores shows a prominent zonal distribution, a feature which has an important bearing on the origin of the deposits. From the surface downward the zones are:

A. Lead-silver zone.

1. Upper, lead-zinc-silver ores with the zinc content increasing at depth.

B. Lead-zinc zone. - 2. Lower, zinc-lead-silver ores with the zinc, copper, and arsenic content increasing downward accompanied by a decrease in the lead content.

C. Zinc-copper zone.

Lead-silver Zone

The deposits from the surface to a depth of about 2000 feet are (Group III) silver-lead bearing ores. They are almost completely oxidized. The ores then are of the argentiferous-galena or the lead-silver zone. The majority of the oxidized arsenic minerals were derived from arsenopyrite. Several of the minerals, especially pyrite and arsenopyrite, were formed over a long period and there is an overlapping of the minerals in the three zones (figure 13).

Deposits in the lower part of the zone which have a similar mineralogical composition commonly occur at different elevations. The ore-bearing solutions undoubtedly emanated from several places and the ores deposited by them were zoned vertically and laterally from the loci. The difference in size of the numerous ore bodies and the relative distance from their sources produced an overlapping of the zones. The bottom of the zone of oxidation roughly marks the lower limit of the argentiferous-galena zone.

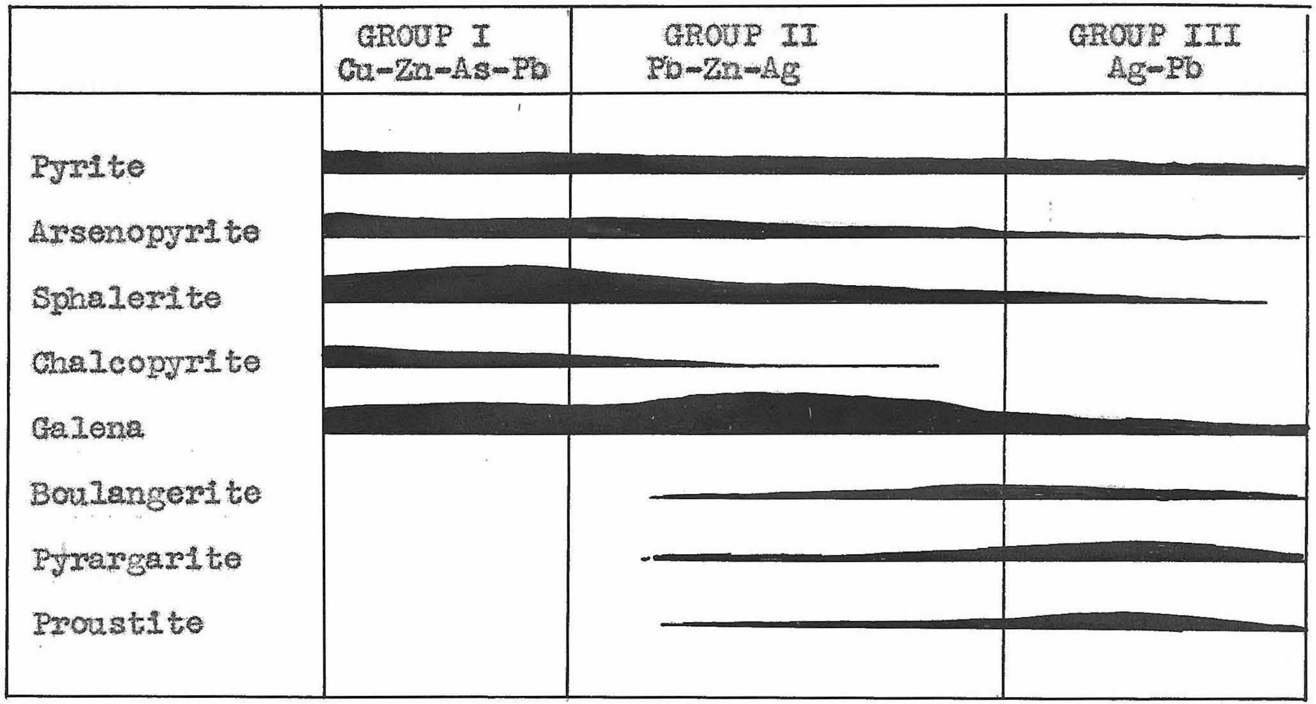


Figure 13. Diagram showing the relative period of formation of the principal ore minerals.

Lead-zinc Zone

Zone B, the lead-zinc zone, passes upward into the argentiferous-galena ores and downward into the sphalerite-chalcopyrite-galena ores. The zone has a vertical range of over 800 feet and may be subdivided into two parts. The upper part consists of deposits of silver-bearing lead-zinc ores in which the zinc and arsenic content increases downward. The lower part of the zone consists of deposits of silver-bearing zinc-lead ores. The lead and silver content of the ores in the lower part of the zone decreases and the zinc, arsenic, and the copper content increases.

The ratio of the difference of the metallic content of deposits which are the same elevation and probably related decreases downward; while the ratio of the differences between the metallic content of deposits which are related to different deep chimneys increases at depth.

Silicates are rare in the gangue of the upper ores of the galena-sphalerite zone, and they become abundant in the ores of the lower part of the zone. Quartz, fluorite, and carbonate are the most abundant of the gangue minerals.

Zinc-copper Zone

The lowermost known ores of the district (Group I) belong to the zinc-copper zone. The ores grade upward into the zinc-lead-arsenic-silver ores of the lead-zinc zone. Within the developed 300 foot range of this zone the silver and lead content diminishes, whereas that of the zinc, copper, and arsenic increases with depth. The gangue minerals are silicates, fluorite, quartz, and carbonate. The silicates increase in abundance at depth.

The mineralogical character of the ores indicate that they probably represent the uppermost part of the copper zone. Arsenopyrite is very abundant, altho very erratic in distribution. However, the arsenopyrite in the ores decreases in quantity from the lowest deposits to the surface.

The succeeding lower zones may be represented at depth either separated or overlapped, or they may be missing. The Barren zone[1] is probably represented by the barren quartz and calcite veins that cut the Bufa limestone of the range.

1. Emmons, W. H. Primary downward changes in ore deposits, Tran., A. I. M. E., 70, 1924, pp. 964-992.

Spurr, J. E. The Ore Magmas. No. 2. 1923, p. 611.

ORIGIN OF THE ORE DEPOSITS

The mode of origin of the manto deposits will be taken up in more detail in another part of this paper. It is well to state here, however, that there can be no reasonable doubt but that all of the deposits of the Mapimi district were formed at one time, and that the ore-bearing solutions were hot magmatic waters. Altho the origin of the ore-bearing solutions is not readily susceptible to positive proof, certain facts indicate that the granodiorite magma was the original source of the solutions.

The solutions forming the lowest deposits must have had a moderately high temperature and the minerals of these deposits are characteristically high temperature or hypothermal minerals such as the garnets, magmetite, fluorite, and the ore minerals, chalcopyrite and arsenopyrite. Upward, as the distance from the granodiorite mass increased, the temperature would naturally decrease and this change is reflected in the mineralogic character of the depositx--garnet, magnetite, chalcopyrite, arsenopyrite, etc., becoming less abundant, or entirely lacking. Sphalerite and galena are among the principal constituents of the ore. Upward, the quantity of the sphalerite decreases. The galena increases in abundance to a maximum in the ores of Group II and then gradually decreases upward to the surface. It seems evident that the

the difference in the metal content of the ores and the zoning is indicative of origin by cooling magmatic solutions.

The zoning of the deposits is well demonstrated, both vertically and laterally. The relation of different ore bodies to each other and to several large chimneys indicates the ore-bearing solutions emanated simultaneously from several places.

The solutions were magnesium-bearing. The originally deposited magnesium minerals were altered during oxidation and locally effected dolomitization. The normal Ojuela limestone, excepting the two described dolomitic beds, is a relatively pure non-magnesium limestone.

The hypogene deposits were massive replacements consisting chiefly of sulphides with a small amount of gangue. Disseminated sulphides distributed thru the limestone are relatively rare. To a small extent the sulphides filled fissures, but for the most part, they were deposited by replacement of the Ojuela limestone without the prior development of open, empty spaces.

The lowermost deposits occur without regard to the known structure, altho there is an alignment of the larger chimneys which suggests the influence of a buried structure or of the granodiorite mass. The location of the upper deposits indicates a partial control of the deposition by the structure.

The ore deposits of the district have been almost completely oxidized from the surface to a depth of over 2000 feet. Therefore, it is necessary to infer from analogy with the lower deposits, and from the few residual masses of sulphides in the oxidized bodies, the nature of the original ores before oxidation began. There is but little doubt that the oxidized bodies originally consisted of masses of sulphides which were chiefly of pyrite, galena, silver-bearing minerals, arsenopyrite, and sphalerite with a gangue of quartz, fluorite, barite, and carbonate. The ores undoubtedly represented those of the lead-silver zone.

The ore-bearing solutions apparently ascended to the site of the known deposits in the zones of intersection of fissures, or fissures and pre-mineral faults that during deposition became the site of chimneys. The fissuring of the limestone varied greatly. The ore-bearing solutions made off from the zone of intersection of fissures when the upward passage was retarded by the relative tightness of the fractures and followed well the fractured favorable beds that were very susceptible to replacement. The gouge along the walls of faults protected the limestone from attack by the ore-bearing solutions in most places and this apparently explains why veinlike deposits are comparatively rare.

The manto deposits, those deposits following the bedding of the rocks, were formed by deposition from ore-bearing solutions that came up along the favorable stratigraphic zone of the manto and not thru the associated vertical fissures. The general form of the Ojuela deposits has been described in a preceding part of this paper together with the structural features that were apparently invariable conditions for mineralization. Fissuring of the limestone is essential for the deposition of the important ore bodies; a fact well demonstrated in the preserved structure of the hypogene mantos.[1]

The development of the ore-bearing and barren caves that are so characteristic a feature of manto deposits are a result of the action of downward moving solutions during oxidation.

The deposits were apparently found at a depth of more than 3000 feet below the present outcrops.

1. See Santa Eulalia report

P A R T IV.

C O N C L U S I O N S .

CONCLUSIONS

A study of the manto type limestone replacement deposits of northern Mexico found under varying conditions led, as might be expected, to the acquisition of data not evident to the geologist whose attention is focused for the time being upon a single deposit.

The deposits studied for this thesis were confined, with one exception, to the eastern part of the Mexican Cordilleran province. The three larger districts have been described in detail in the accompanying papers.

The deposits consist in general of a connected series of manto and chimney ore bodies. Mantos are long narrow blanket-like ore bodies which follow the bedding; chimneys are irregular elliptical-shaped bodies which traverse the bedding of the enclosing rocks.

Some of the points applicable to the study as a whole are set forth in the following summary:

1. The Lower Cretaceous sedimentary rocks of northern Mexico are a continuation of the Texas Comanchean formations.

2. Correlation of the formations in northern Mexico with those of the Texas Comanchean series permits a more restricted stratigraphic assignment of the ore-bearing zones

than is possible with the European system of nomenclature.

3. Most of the mantos occur in the Black and the Los Lamentos limestones of the Trinity division of the Comanchean series. The Intermediate limestone, the uppermost member of the Trinity division, is relatively barren in most districts. The lower part of the Bufa formation of the Fredericksburg division has a number of ore-bearing zones and in some districts it contains the major deposits.

4. The mantos are confined to certain beds or zones. The number of favorable ore-bearing zones in a formation varies over the province, altho locally, the ore-bearing horizons are continuous. The factors which make some beds or zones more susceptible to replacement than others have not been satisfactorily determined. The data, however, show that it is the physical and not the chemical properties of the limestones that apparently exert the greatest influence upon the location of manto deposits.

5. The majority of the mantos are found at the crests of folds. The folds may be prominent or, in little deformed regions, can be discerned only by careful investigation. The fracturing is most pronounced at the crests of the folds.

6. The fissures are rarely single breaks which are prominent over a great vertical range. The breaks usually

occur in groups or belts of closely spaced parallel fractures. They were formed apparently by tensional stresses.

7. The character of the fracturing is, in part, dependent upon the physical properties of the limestone. In brittle beds the fracturing is pronounced, while in others, especially the argillaceous layers, the fractures are relatively 'tight.' Hence a fissure zone in its vertical range may be strong in some beds and very tight or lacking in the intervening layers. The beds which were most susceptible to fracturing furnished favorable channels for the ore-bearing solutions which by replacement produced the manto deposits.

8. Intersecting fissure zones produced a rough column of broken rock, which afforded not only a channel for mineralizing solutions but also a site for chimney deposits.

9. The fissures are more pronounced and continuous in depth.

10. Mantos are invariably associated with pre-mineral fissures. This feature may be almost obliterated in the oxidized deposits but is an outstanding feature of the primary deposits.

11. Within an ore-bearing horizon the manto deposits gradually step from the lowermost to the uppermost favorable beds of the particular horizon and follow the upper layers until another chimney or the surface is reached.

12. Altho the cross section of the deposits decreases upward from the lowest known bodies of a district, the diminution is not constant but varies with the physical condition of the enclosing rocks. Strata in which the fracturing and faulting was pronounced and at the same time uneven in magnitude contain deposits which have very irregular cross sections.

13. Folding, altho it may be quite gentle, was a very important factor controlling the location of the manto deposits. During folding, which apparently was accompanied by fracturing, the brittle beds broke and the more competent layers were folded. Differential movement of the beds produced gouge which acted as impervious barriers to the ore-bearing solutions.

14. Vein deposits are rare. This is, in part, a result of the inconsistent character of the fissures over a large vertical range and the absence of pronounced pre-mineral faults in most districts. The walls of the faults where present were apparently protected by gouge from the action of the mineral-bearing solutions which may have passed thru them.

15. In districts where the deposits have been worked over a considerable vertical range, mantos have furnished the largest production in the upper part of the deposit and chimneys become increasingly important in depth. This is,

in part, caused by the increased prominence of the fissures in depth.

16. Altho the analyses of sections of an ore body, either oxidized or sulphide, are uniform; the deposits show a gradual but very definite change in composition over the entire district.

17. There is a blending of the minerals formed at different temperatures which demonstrates a gradual transition from a higher to a lower temperature environment.

18. The ores are believed to have been deposited by magmatic waters. The deposits of a district were apparently formed at one time. The similarity of the districts and the general geological association indicates that the manto deposits were probably all formed during early Tertiary time.

19. The ores are zoned upward and outward from the apparent source of the mineral-bearing solutions.

20. Replacement deposits associated with parallel fracture zones in different manto horizons or diverging fracture zones in the same horizon may have a very different composition at points equidistant from the presumed source.

21. Oxidation has changed both the chemical and physical status of the deposits.

22. The metallic content of the bedded oxidized material is roughly that of the primary deposits from which

it was derived. This indicates that during oxidation there was no removal for any great distance of any of the economic minerals.

23. Magnesium minerals, constituents of the primary deposits, were altered during oxidation and the limestone locally converted to dolomite. Dolomitic limestone in the vicinity of primary deposits is rare.

24. The caves associated with the oxidized deposits are products of oxidation. The ore-bearing caves were formed by the lowering of the oxidized ores from the position of the primary manto thru the removal of limestone beneath the deposit by acid solutions. The action expedited by collapse which continued until the roof became a stable arch. The barren-caves formed during oxidation mark circulation channels.