XEROX COPY

OF 186

# GEOLOGY OF ~~THE~~ LUIS LOPEZ MANGANESE DISTRICT, NEW MEXICO

by
Max E. Willard, 1973
34 illustrations

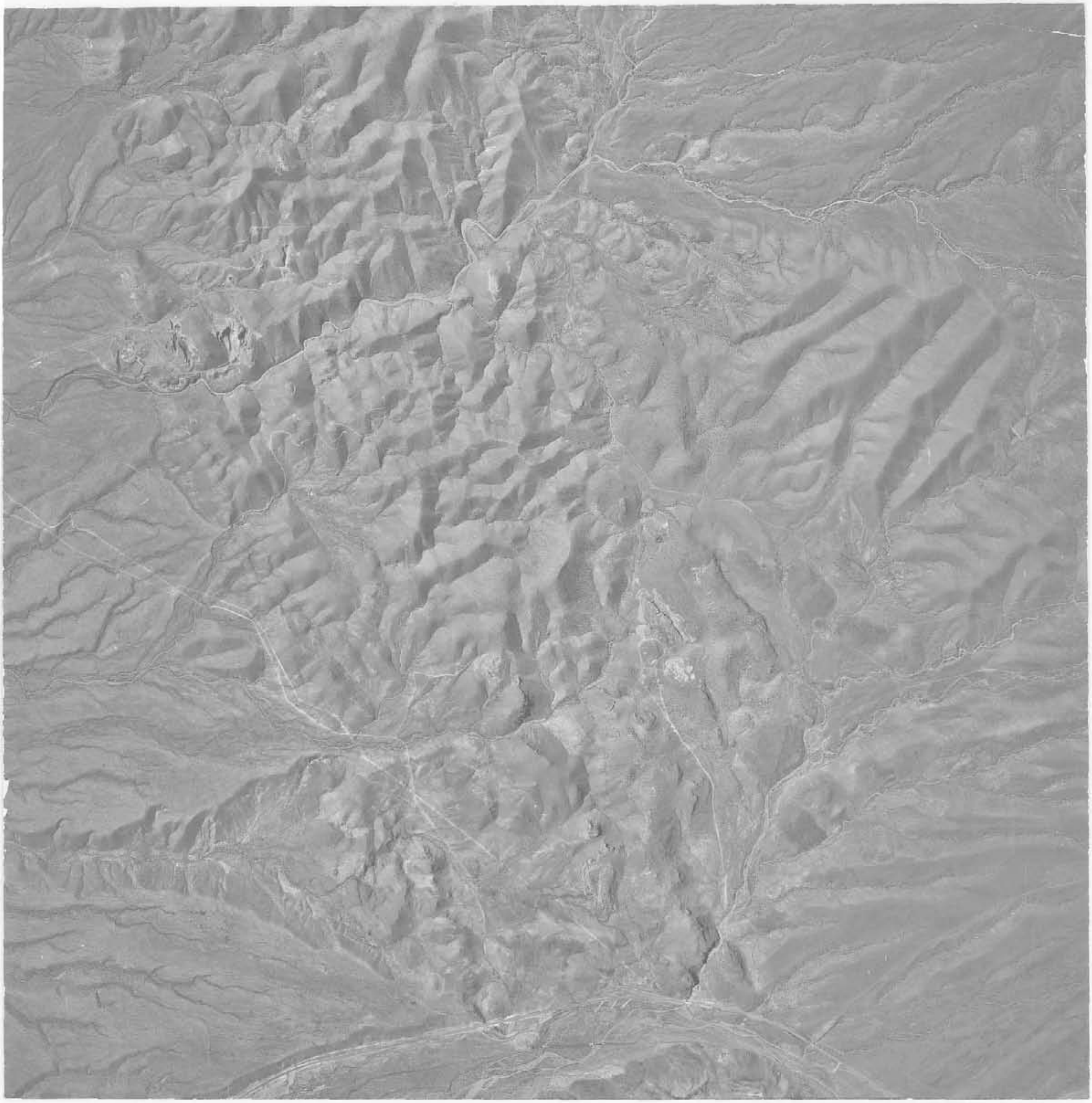
Note: I am convinced that the red-brown editing was done by Max. The corrections are minor in nature following page 58. In fact the last figure number (fig. 22) inserted in ms appears on this page — indicating that subsequent numbers were not completed, even though planned as indicated by blank spaces left in ms beyond p. 58.

VCKelley 10/31/73

note: plates 1, 2, & 3 referred to in this m.s. not yet located
RWE 19

# CONTENTS

Frontispiece



Aerial view of Luis Lopez Mining District. U. S. Highway 60 and A. T. & S. F. R.R. at north (top) of view. Scale: 1:40,000; Frame 003, NMBM&MR flight, 11 September, 1967; imagery by Koogle & Pouls Engineering, Inc., Albuquerque

# INTRODUCTION

## Purpose and Scope

The Luis Lopez district has been the most productive manganese district in New Mexico. Most of the surface exposures of manganese have been previously tested and no exploration or prospecting is presently being done. If future exploration and development of the district is to occur, a thorough knowledge of the genesis of the deposits and of the regional geology is required. For this reason the New Mexico Bureau of Mines and Mineral Resources undertook a detailed geological-geochemical reexamination of the district. It is hoped that the results of this examination will be helpful in the future when development of these deposits becomes necessary. It is also hoped that the data recorded in this report will contribute to a better understanding of this type of manganese mineralization and will be a useful guide in the exploration and development of similar deposits elsewhere.

## Methods of Investigation

In 1962, D. F. Hewett of the United States Geological Survey suggested that the New Mexico Bureau of Mines restudy the geology of the Luis Lopez manganese district; for the reason that there was then definite interest in the nature of the downward extension of the manganese veins. The recommended restudy was subsequently initiated.

No adequate base maps were originally available, hence mapping was started on 1:24,000 air photographs, but it soon became evident these were also inadequate. Hence, new air photographs were taken and a multiplex base map at 600 feet to the inch and a contour interval of 20 feet was prepared for the Bureau by Koogle and P~~a~~ouls Engineering of Albuquerque. Colored air photographs of the district were also taken. A geologic outcrop map of the district was completed using the new base. In addition topographic and detailed geologic maps at a scale of 200 feet to the inch of the principal mine areas were made.

Samples of the area ore minerals were systematically taken from the principal mines and most of the numerous prospect pits. A geochemical study of these samples was made, and the variations in percentage of minor elements and their distribution in the district were determined. The distribution of minor elements with respect to ore mineral structures and texture was determined by electron probe analyses.

Ore and gangue minerals were identified optically and in part by chemical analyses and x-ray. Ore mineral texture and structure were studied megascopically and microscopically. Much important information concerning the volcanic stratigraphy and its relation to the distribution of ore minerals was obtained from an exploration hole drilled at the Tower mine for the Mountain Copper Mining Company.

## Previous Work

The first general study of the Luis Lopez district was done in 1951 and 1952 by A. L. Miesch. The results of this study furnished the geologic foundation for most subsequent investigation of the district. In 1955 E. C. Anderson and H. L. Jicha, Jr. then on the staff of the New Mexico Bureau of Mines and Mineral Resources began a detailed study of the principal manganese deposits, but only preliminary results were published. D. F. Hewett visited several of the deposits and collected many ore samples. In 1964 he published short geologic descriptions of several of the deposits and many detailed descriptions and spectrographic analyses of the ore. A report on the manganese deposits of New Mexico by L. L. Farnham of the United States Bureau of Mines was published in 1961. It contains descriptions including location, history, production, ownership, geologic setting and mining methods of most of the mines in the Luis Lopez district.

## Acknowledgments

The writer is indebted to A. J. Thompson former director of the New Mexico Bureau of Mines and Mineral Resources for his continued interest and especially for making possible the taking of the air photographs and preparation of the multiplex base map. The writer is also indebted to Don H. Baker Jr. director of the Bureau whose continued interest and urging significantly encouraged the completion of this report.

An expression of appreciation is due P. D. Hillard for his assistance both in the field and laboratory. Mr. Hillard is responsible for most of the emission spectrographic analyses. Thanks are due to ~~I.~~ L. A. Goret and ~~U.~~ V. Aguilar former operators of the Black Canyon and Nancy mines, for permission to examine the underground working at these deposits.

D. F. Hewett's assistance in the initiation of the Luis Lopez project, plus his continued encouragement and stimulating ideas contributed much to the progress of the work and are sincerely appreciated. It is a pleasure to acknowledge the considerable help given by many members of the Bureau staff. Without their support this report could not have been completed.

# GEOGRAPHIC FEATURES

## Location and Accessibility

The Luis Lopez mining district lies at the north end of the Chupadera Mountains approximately 6 miles southwest of Socorro and about 5 miles west of the villages of Luis Lopez and San Antonio. Both these villages are on the El Paso line of the Atchison Topeka and Santa Fe railroad. A branch line of the same railroad extends from Socorro to Magdalena and crosses the north end of the district along Socorro Canyon. Highway U. S. 60 similarly crosses the district. Interstate 25 roughly follows the course of the Rio Grande River five miles to the east. Numerous ranch and mine roads make most of the district readily accessible.

## Physical Features

The Chupadera Mountains, in which the manganese deposits occur, are a southern extension of the north-south trending Socorro, Polvadera, Lemitar mountains structural highland. They are bordered on the east by the terraced deposits of the Socorro Basin part of the Rio Grande depression, and on the west by a southern extension of the Snake Ranch Flats. West of these flats are the high peaks of the Magdalena Mountains.

The maximum elevation in the district is 6277 feet, and the relief is a little over 1000 feet. Within the mining area the topography is rugged, with many steep slopes and deep canyons. Most of the drainage is from west to east approximately at right angles to the crest of the Chupaderas. Many of these streams follow deeply incised meandering courses. There are no permanent streams in the area and only one spring. Local wells supply the water needed for stock and domestic use. Sufficient water to operate the manganese mills was obtained from wells in the Rio Grande valley sediments just off the east edge of the mapped area.

## Climate and Vegetation

The climate is warm and dry. The average temperature at Socorro is 57°, and is not appreciably lower at the mines. Extremes of heat and cold are rare. Average annual rainfall in the area is about 11 inches most of which occurs from July to October. Snowfalls are infrequent and seldom remain more than a few days.

Vegetation is scanty. A thin grass cover and scattered nopal (prickly pear) grow on the higher slopes. Greasewood, mesquite, yucca, beargrass, and challa are most common on the flats boardering the mountains. Squawbush, scrub/oak, and challa occur in the ~~boarder-~~ mountain valleys.

## History and Production

A small amount of manganese ore was produced from the Luis Lopez district during World War I. During World War II the mines were again active and production continued intermittently until 1951. In November 1951 the General Services Administration under the Defense Production Act opened a manganese-purchasing depot in Deming, New Mexico. As a result, production from most of the Luis Lopez mines was resumed and continued until the depot closed in 1955. Only the mines that had milling facilities could meet the specifications of the General Services Administration's "carload-lot" purchasing program and they continued in production until 1957. After termination in 1957 of the government purchasing programs, only one mine was able to remain in operation. In 1970 it also was forced to shut down due to the increased costs of mining.

The Luis Lopez manganese district has been one of the most productive in New Mexico and by far the most productive in Socorro County. The total ore mined up to 1958 is estimated to have been slightly in excess of 1.5 million tons. The crude ore ranged from a few percent to about 28 percent manganese, and hence most of it had to be concentrated to meet the specifications of the purchase programs.

From 1958 through 1966 the total reported production was about 32,000 tons. All production from 1966 through 1970 came from one mine and therefore, to avoid disclosing company data, was not reported. Production during this period is estimated to have been between 10,000 and 15,000 tons.

## Mines and Prospects

Locations of the principal mines and prospects in the district are shown in Figure 1. Most of the smaller prospect trenches and pits are shown in the geologic map Plate 1.

Production has come mainly from three deposits, the Black Canyon, Tower-Nancy, and Red Hill-Red Hill Extension. The last named is locally referred to as the MCA mine in referrence to the fact that it was operated by the Manganese Corporation of Arizona.

The Tower and MCA deposits were mined in open pits. Heavy earth moving equipment was used at both these mines. The Black Canyon and Nancy were worked underground by cut-and-fill stoping.

Prospecting has been extensive throughout the Luis Lopez district. Most of it has been limited to surface pits and bulldozer trenches. A few short adits have been driven and one deep exploration hole was drilled. Approximately 70 prospect excavations have been examined. Most of these and the developed mines are located in the high central parts of the Chupadera Mountains.

Much of the district is covered by mining claims held by various individuals and companies. Two small tracts of land in sections 5 and 20, R 1W, T 4S are private land, the rest is either State or Federally owned.

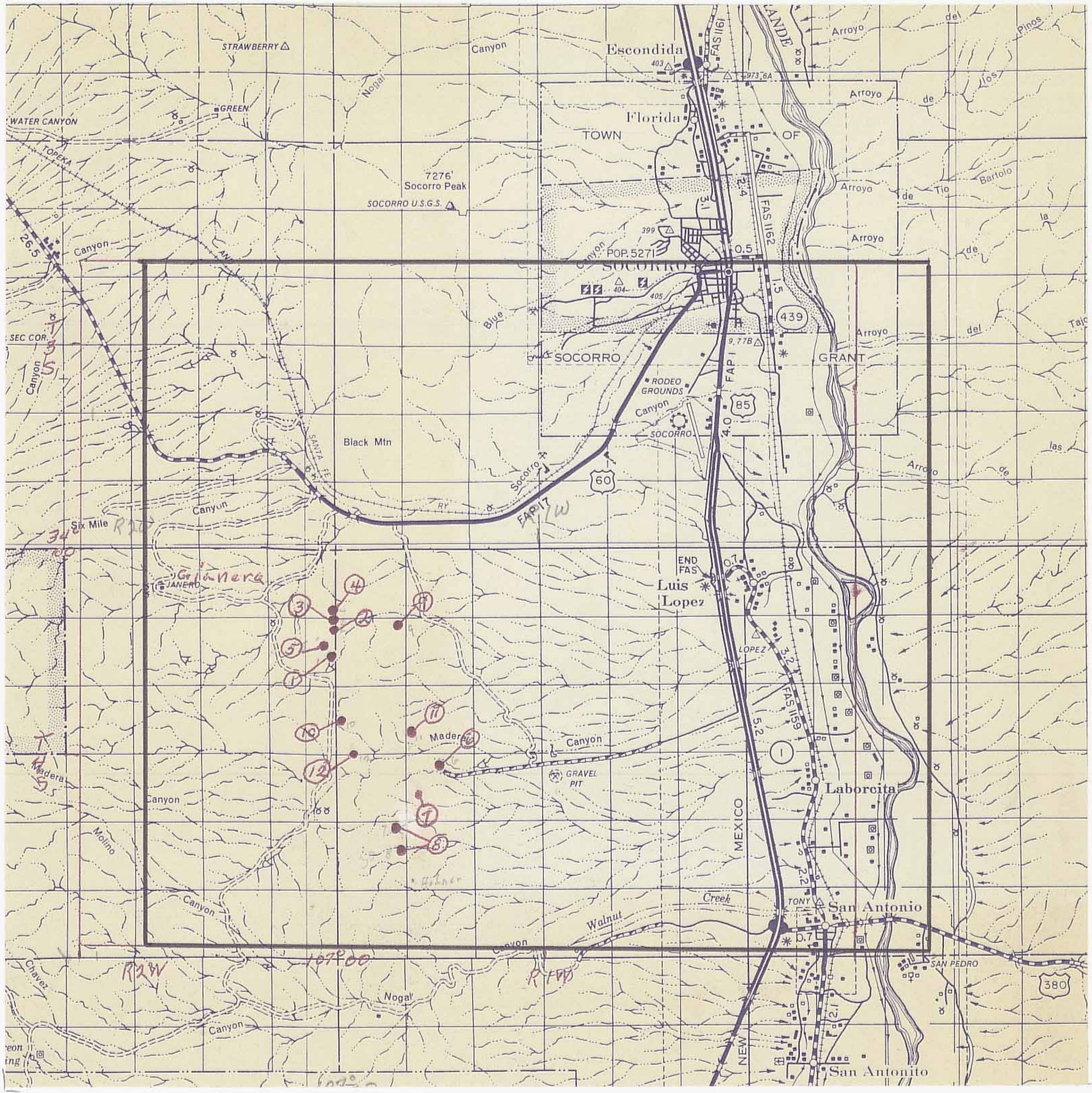


Fig. 1: Principle mines and prospects, Luis Lopez Mining District, Socorro County, New Mexico

1) Black Canyon (Udg)
2) Tower -Nancy (Udg)
3) Barrett (Gloryana)
4) Optimo (Blue Gold)
5) Geronimo
6) MCA (Red Hill/Red Hill Extension)
7) Black Crow - San Juan
8) Esperanza
9) Bursum (Griffith)
10) Torres (M&M Group)
11) Big Basin
12) Pretty Girl

OFR 186 following p 5 #11

## Milling Methods

Two heavy media plants were in operation in the district between 1954 and 1958. One operated by the Tower Mining and Refining Company was about 1/2 mile south of Socorro and highway U. S. 60. The other operated by the Manganese Corporation of Arizona was $1\frac{1}{2}$ miles east of the Red Hill pit. Farnham (1961) reports that the plant built by the Manganese Corporation of Arizona was the first plant of this type in the United States to be used exclusively for the treatment of manganese ores. Both plants were located on the flats of the Rio Grande basin just east of the Chupadera Mountains. Water for the operation of these plants was obtained from wells in the basin fill.

A small crushing and screening plant owned by the Black Canyon Mining Company was in operation through 1970. This plant is near the south edge of Socorro on highway U. S. 60. Ore from the Black Canyon and Nancy veins selectively mined, and screened in this plant was upgraded to a marketable product.

At present part of the buildings at the MCA mill are still standing, most of the equipment has been removed. Nothing but the waste dumps remain at the site of the Tower mill. The crushed rock in these dumps is being used in Socorro as driveway fill, ground cover, and in other ways and as a result a small business has developed around the hauling of this material. The Black Canyon crushing and screening plant is still complete and in operating condition.

# DESCRIPTIVE GEOLOGY

## Introduction

The lowlands surrounding the Chupadera Mountains are underlain by the Tertiary basin-fill sediments of the Popotosa and Santa Fe formations. The Popotosa is principally playa clays and silts. The coarser deposits ~~have been~~ were previously correlated with the Santa Fe, but the reliability of this correlation is questionable.

Structurally the Chupadera Mountains are an elevated and complexly faulted block of Tertiary volcanic rocks. Within the Chupadera horst are several divergent fracture systems that have little apparent systematic relationship to each other. The Popotosa and Santa Fe formations were involved in this faulting and at places the Recent alluvium appears to be offset. At present the area is seismicly active.

The volcanic rocks of the Chupaderas although not traceable into the Datil formation, were originally correlated with that formation. The oldest unit is a highly altered latitic tuff. Above this is a series of rhyolite flows and pyroclastics. Typical welded tuff (ignimbrite?), crystal tuff, vitric tuff, and tuff breccia are represented. Intravolcanic sandstones occur at places. Intralayed in this pile of rhyolitic rocks is one relatively thin basaltic-andesite flow. ~~Below this known rocks must be additional volcanic xenoclasts of andesite.~~

Manganese oxide minerals are widely distributed in primary cavities in the rhyolitic pyroclastics. However all the larger productive deposits occur in breccia zones in a crystal tuff. The manganese deposits are considered to be hypogene.

## Pre-Tertiary

Rocks older than the Tertiary are not exposed in the Luis Lopez district and therefore their nature can only be inferred. Precambrian granite and argillite; Mississippian, Pennsylvanian, and Permian limestone, shale, and quartzite are present in the Magdalena Mountains a little over 15 miles to the west. Precambrian gneissic granite and Pennsylvanian sediments are exposed on Socorro Mountain approximately 5 miles north. About 6 miles south of the district near the crest of Chupadera Peak in the Pedro Armendaris Grant are exposures of Precambrian and Pennsylvanian rocks.

Large cognate clasts and xenoclasts are present in all the rhyolitic pyroclastic unites of the district, but are most abundant in the crystal tuff. Xenoclasts of granite, simple pegmatite, granite gneiss, amphibolite, phyllite, and quartzite are very common and fine grained limestone, sandstone, and siltstone have been observed. Angular inclusions of coarsely crystallized calcium carbonate are present in a tuff breccia in the upper parts of the volcanic section. Alterations of many of these inclusions has left a skeletal residue of quartz and Sanadine. Probably these altered inclusions were originally limestone. The number of large xenoclasts of all types increases from north to south, but the ratio of metamorphic to nonmetamorphic types remains about the same.

From the above it appears likely that Carboniferous and possibly Permian rocks are present at places in the Chupadera Mountains below the volcanic sections. Elsewhere the underlying rocks are Precambrian.

## Tertiary Volcanic Stratigraphy

A thick sequence of volcanic units is exposed in the Chupadera Mountains. The oldest unit, known only from diamond drilling, is a Satitic tuff. Above this tuff is a series of rhyolite flaws and pyroclastics. Typical welded tuff, crystal tuff, vitric tuff, tuff breccia, and coarse volcanic breccia are represented. Intravolcanic sandstone layers occur at places. Interlayed in the pile of rhyolitic rocks is one relatively thick composite unit of andesitic basalt. Several of the stratigraphic units in this volcanic sequence pinch-out within the mapped area, and others change rapidly in thickness. The lithology of some of the volcanic units changes from place to place, these variations in lithology and thickness are shown diagramatically in the three composit sections of Plate 1.

Latite Tuff (Tlt)

This unit~~s~~, as has been pointed out, is the oldest exposed volcanic rock in the district. The only surface exposures are in a cut on highway U.S. 60 near the northeast corner of the mapped area. Approximately 380 feet of this tuff was also encountered in a diamond drill hole at the Tower mine. The rocks at these two localities are somewhat different, but both directly underlie a very distinctive rhyolite flow and therefore are considered equivalent.

In the road cut the tuff is well stratified, white to light gray, friable ash tuff. Individual beds range in thickness from a few inches to several feet. In the drill hole and at the road cut it is highly altered. The road cut material, as indicated by x-ray analysis, contains a high percentage of montmorillonite.

The tuff in the drill hole is light gray and contains scattered phenoclasts of quartz, chalky white feldspar; and small partially altered fragments that were originally andesite. In thin sections many of the quartz clasts are highly rounded and corroded. There are few quartz euhedra, most grains are angular. All the feldspar clasts are in part altered to calcite. This alteration is most intense along cleavage planes, however a few grains have been completely replaced. The unaltered parts of the feldspar are unstained by cobaltinitrite and this combined with the optical data obtained suggest they were originally plagioclase. Wart-like intergrowths of quartz and feldspar suggest that some quartz was introduced. The ground mass is a very fine grained crystalline aggregate of quartz and either potassium feldspar, sericite or both. A part of the quartz in the groundmass occurs in microscopic veinlits which also suggest it was intraducted.

A few structures that may be relict shards are still present. The groundmass is highly stained by cobaltinitrite which suggests the presence of a higher percentage of potassium than would normally be expected in a latite. Similar anomales amounts of potassium are present throughout the sections, even in the sandstones, which suggests the pervarine circulation of high potassium bearing solutions.

Because of the relatively high percentage of playioclase plus the observed textures and structures the rock is assumed to originally have been a latite tuff that has since been highly altered.

In the diamond drill approximately a hundred and ten feet of waxy fault gange cuts across this tuff. Green clay seams are present in this gange and the altered tuff. X-ray analyses indicate this clay is largely hydromica with a small amount of K-feldspar, possibly adularia.

## Flow Banded Rhyolite (Tfr)

The flow banded rhyolite as described here includes the "spherulitic rhyolite" and the "late rhyolite" of Miesch (1956). It is the product of a single rhyolitic erruption and is stratigraphically conformable with adjacent parts of the section. Outcrops occur north and south of highway U. S. 60 where it crosses the first ridge of hills, and east of Black Canyon opposit the Tower mine. These areas of exposure are in structurally elevated blocks. Approximately 150 feet of this rhyolite was present above the latite tuff in the Tower drill hole.

In general the rhyolite is thinly laminated with alternate layers ranging from white to dark gray, and from a few millimeters up to several inches thick. The lighter colored layers appear pumiceous. The dark layers are aphanitic, and may be divitrified glass. The rock has a tendency to split along the laminations, producing a platy talus. Highly contorted flow-folds are common, especially in the area near highway U.S. 60. Spherulites ranging from microscopic to an inch or more across are characteristic. It appears that these are more numerous and the flow folding is more intense in the lower parts of the flow. Scattered small phenocrysts of quartz, potassium feldspar and biotite are common.

Nowhere in the district is the bottom contact of this unit exposed. However, the surface relations and information from drilling suggest its thickness may change rapidly from place to place. Approximately 150 feet of flow banded rhyolite were encountered in the Tower drill hole. In the mountain just to the east of the mine it must be much thicker. This greater thickness is indicated by the relationship of outcrops to topography. Interpretation of these data in terms of the location of the eruptive center would be hazardous. The rhyolite east of the Tower mine was previously considered intrusive.

Intravolcanic detrital sandstone (Tvs). Detrital sediments are less common in the stratigraphic section than would be expected. They are known only from two small areas of surface exposure and from one section of drill core. At each of the occurrences the sediments are medium to coarse, pink to brick red, crossbedded sandstone. The sandstone bed in the Tower drill hole is approximately 100 feet thick, and the thickness of the beds exposed at the surface appear to be about the same. The surface outcrops are on the crest of the ridge east of the road between Box Canyon and the Tower mine. The sandstone in the northern most exposures overlie a coarse breccia. In the southern outcrops it is interbedded or underlies the rhyolite tuff breccia. In the drill hole it overlies the flow banded rhyolite, and is much lower in the stratigraphic section (Plate 8). These sandstone beds are limited areally, are megascopically very similar and therefore are not helpful marker beds.

In a thin section of drill core the sandstone is medium grained, moderately sorted, and contains mixed angular and rounded grains, largely of feldspar and quartz. The presence of both sanadine and albite was verified optically and by staining. Partial alteration of the albite occurs along cleavage planes, minute fractures and in rims parallel to the grain boundaries. A grain count gave 12 percent sanadine; 60 percent albite, with a wide range of 2V; and 28 percent quartz. The section contained less than one percent lithic fragments and these were all from the underlying flow banded rhyolite. The grains are set in a dense cement of hematite, microcrystalline quartz, potassium feldspar, and possibly sericite. An intense cobaltinitrite potassium stain developed on this cement and alteration products from the albite. Most of the larger feldspar grains were uneffected. The alteration in the sandstone and associated volcanic rocks is similar and apparently the result of the same processes.

A drusy cavity encountered at 834 feet in the diamond drill hole contained barite crystals up to 3 mm. across. Most of these crystals are stout and are bounded by pinacoidal faces.

## Rhyolitic Tuff (Trt)

This tuff is exposed in a small area south of Blue Canyon and was encountered in the Tower drill hole (Plate 3). Its upper contact was 718 feet below the collar of the hole. It underlies the crystal tuff and overlies the intravolcanic sandstone. It is light tan to white, fine grained, pumiceous tuff. Scattered phenoclasts of quartz; feldspar, some of which shows a blue schiller effect; and bleached golden biotite are megascopically recognizable. Fragments of fine grained andesite, brown glass, and pumis, occur throughout this unite.

Optically both albite and sanadine were identified. Albite, the most abundant feldspar, has a moderate 2~~A~~V and was unstained. It is unaltered and untwinned. The grains are irregularly angular and clearly are not the result of secondary albitization. The sanadine is present in small amounts and is characteristically altered. Argillic alteration rims that give a strong potassium stain, are common. This alteration has also penetrated the grains along cleavage planes. Quartz phenoclasts are most abundant. A few grains give anomalous biaxial interference figures.

The groundmass of the rock is made up of devitrfied or partially devitrified shards that are crowded with fine tubular vesicules (~~Photo~~ ). Specular hematite denbrites are common. Much of the hematite fills in around the shards but a part was deposited within the ~~fine~~ tubular vesicules.

## Crystal Tuff (Tx)

The crystal tuff is the most widespread and thus far the most economically important volcanic rock in the Luis Lopez district. It is the host rock at all the significantly productive manganese mines, and most of the prospects. It is the central core of the Chupadera Mountains from just south of highway U. S. 60 at the north to Nogal Canyon approximately two miles south of the map boundary (~~Photo~~ ). This is the rock Meisch (1956) called "massive rhyolite". He believed the northern part was intrusive into the older volcanic rocks and to the south was extrusive. Microscopic studies of rocks from both areas plus recent diamond drilling and mapping all indicate that this unit is everywhere a pyroclastic extrusive. The apparently intrusive field relations are due to faulting.

The upper contact is exposed at several places north and east of the Tower mine and was cut in the diamond drill hole. It is also well exposed east of the Black Crow and Esperanza prospects south of the MCA mine. In the drill hole and at the surface exposures the crystal tuff is overlain by a dense black basaltic andesite. The lower contact is exposed south of Blue Canyon and was cut in the Tower drill hole. At the drill hole it is underlain by the pumiceous tuff and [illegible] is approximately 630 feet thick, elsewhere in the district it may be appreciably thicker.

Miesch estimated a maximum thickness of about 1000 feet.

The coarse stratification regionally present in the crystal tuff suggests that in the Chupadera Mountains the tuff is a composit that includes the products of several relatively closely spaced eruptive episodes. In general this pile of stratified pyroclastics has been tilted to the east. Hence, the changes along the west side of the mountain represent the expectable areal changes within a single eruptive unit. The stratification from west to east is the product of a series of successively younger eruptions. This stratification is of such a nature that it is not easily recognized in the field. It becomes most evident when viewed from a distance. The several eruptive units tend to weather differentially producing a series of low topographic ridges. These ridges are best developed along the eastern front of the range, and can be seen clearly on the air photograph~~s~~ (~~figure~~ ___). (Frontispiece)

The crystal tuff ranges from brick red through pink to gray, and characteristically contains an abundance of crystal debris. Phenoclasts of quartz, feldspar, and biotite are present everywhere and at places constitute as much as 30 percent of the rock.

All of the crystal tuff is welded, but the intensity of welding is greatest near the base (Plate 3). The lower 100-150 feet of crystal tuff in the Tower drill hole are highly welded and contain only a few percent of phenoclasts. The matrix is dark reddish brown, very fine grained to almost gl~~o~~assy, and brittle with a typical conchoidal fracture. The same highly welded rock is exposed in the lower levels of the Black Canyon mine. At both places the lower parts are less altered than the rest of the tuff, most of the feldspar grains still show characteristic sanadine opalescense. Small cavities containing tiny quartz crystals are present in drawn out gray pumiceous streaks and blotches. This lower part, in contrast to the rest of the unit, contains only a few small xenoclasts of earlier andesite. Upward in the diamond drill hole the crystal tuff is pink streaked with gray. Andesite xenoclasts and mineral phenoclasts are abundant. Primary porosity is high due to local vesiculation and due to partial healing of contraction and compaction fractures. Many of these cavities contain scattered half-beads and rosettes of manganese oxide on their walls (~~Photo~~ Fig. 2 ), in others the walls are covered by thin paint-like films also of manganese oxide. Spectrographic analyses were made of the manganese minerals in these isolated cavities and the results are reported in a following section of this report.

Regionally the physical character of the crystal tuff changes from place to place. At the north, as represented by the diamond drill core, it is rather massive and dense, with few xenoclasts of limited rock types. Stratification within this northern part, if present, is not evident in outcrops. South along the west side of the range and roughly at the same stratagraphic horizon the number and size of xenoclasts increases markedly, and many different rock types are represented. Xenoclasts of all the older volcanic rocks are present. Clasts of a dense black andesite are especially abundant. Similar andesite clasts as already noted are present in the latitic and pumiceous tuff, below the crystal tuff. This andesite which must underlie these rocks does not crop out in the mapped area. In addition, as was pointed out in the discussion of pre-Tertiary rocks, the crystal tuff in the southern areas contains many fragments, some more than a foot across, of granitic gneiss, simple pegmatite, amphibolite, phyllite, and quartzite. Xenoclasts of sandstone, siltstone, and fine grained limestone are also abundant. Many of the outcrops are highly cellular due to the weathering out of the smaller fragments of these sedimentary rocks. Initial cavities are also common and a eutaxitic structure is well developed parallel to an otherwise poorly defined textural stratification.

At the north end of the exposures only the massive (~~densely~~ basal) parts of the crystal tuff are present. In the area of the Tower mine, for example, the products of subsequent crystal tuff eruptions were not deposited and the massive tuff is overlain by an andesite flow. In the center part of the district the massive tuff is overlain by a coarse breccia of crystal tuff in a crystal tuff matrix. Characteristically the breccia

Fig. 2: Half-heads and rosettes of manganese oxide in cavities in the srystal tuff.

OFR 1866

following p 16

fragments are a few inches across, but locally may be much larger. This breccia is not tectonic but a result of the eruptive process. In the area of Big Basin the coarse breccia is well exposed in a wide north-south trending zone. The clasts in this breccia change in size across and parallel to the trend of the regional stratification, which suggests that the unit is made up of a series of relatively thin lenticular layers. The xenoclast assemblage is the same as in the underlying massive tuff.

Exposures of very coarse crystal tuff volcanic breccia occur in two structurally isolated areas near the Tower mine (Plate 1). The clasts in these exposures are texturally and compositionally similar to the crystal tuff at the pit. They are closely packed and set in a dark red lithoidal groundmass. The exposures north of the mine are overlain by the [illegible] andesite flow that is exposed in the pit area. Downward this breccia grades into the massive tuff. The eastern exposures appear to grade laterally into massive tuff. Outcrops of this coarse breccia are also present on the lower slopes south of the Black Canyon mine, here also they appear to grade into massive tuff. Hence, this breccia probably developed locally, and although physically similar to the breccia at Big Basin should not be correlated with it.

The main ridge east of Big Basin is made up of a series of subdued hogbacks that trend north-northeast and dip east ~~(Fig. ___)~~. The west face of the ridge is a fault scarp. So that, although the rocks of this ridge were not observed resting directly on the coarse breccia phase of the crystal tuff, they do stratigraphicly overlie it. They are the uppermost exposed parts of the crystal tuff.

These upper parts of the crystal tuff are well stratified, individual layers range from a few inches to several tens of feet thick. Differential weathering of the layers has produced the low hogbacks shown on the airphoto ~~(Fig. ___)~~ (Frontis piece). At places the rock is a breccia, but it contains fewer angular fragments and they are generally smaller than in the underlying units. Autoliths are common and the assemblage of xenoclasts is the same as observed in the rest of the crystal tuff. The upper layers are moderately porous and locally appear vesiculated parallel to the stratification. At the north end of the hogbacks the quartz and feldspar phenoclasts are larger than elsewhere. In general the layers are friable and hence are easily weathered. Slope debris is characteristically granular or platy and many of the outcrops appear coarsely cellular. The layers range from gray to reddish, but shades of gray predominate. Locally these upper layers are streaked by discordant bands that are stained bright red by iron oxide or bleached a chalky white. Most of the bands can be related to crosscutting fractures or small dikes. All of the crystal tuff shows evidence of welding but it is clear from the above descriptions that the degree of welding in the upper layers is less than in the rest of the tuff. As in the rest of the crystal tuff, isolated veinlets and pods of manganese oxides are scattered throughout these upper layers. They apparently are most common at the south end of the ridge for, although outcrops are not good in this area, nuggets of manganese oxide are abundant in the regolith.

The clastic nature of the crystal tuff is most evident in thin sections. It contains phenoclasts of quartz, alkali feldspar, oligoclase, and biotite in a groundmass of microcrystalline quartz and potassium feldspar. Streaks of fine dusty hematite in the groundmass wrap around the larger mineral clasts and are oriented conformable with a megascopically evident flow structure. In most sections the intense welding and devitrification~~s~~ have obliterated all traces of former shards. However, in a few sections relict shards are still evident because of the presence of an original dusty matrix.

Fragments of albite and orthoclase a few millimeters across are abundant, and of the two albite is the most common. Both feldspars have indices well below canada balsam, are generally untwinned, are without evident perthic structures, both have relatively large optic angles, and megascopically display the pearly opalescence of moonstone. Oligoclase was identified only in a few sections. In these it was highly altered to a potassium rich microcrystalline aggregate of clay and sericite.

Quartz phenoclasts are ubiquitous in the Crystal tuff but generally are less than 10 percent of the rock. Morphologically the quartz grains range from euhedral through sharply angular to well rounded. Angular grains are by far the most common, euhedral and rounded grains are rare. The angular and euhedral grains have sharp well defined boundaries and there is no evidence of interaction between these grains and the matrix. The rounded grains in the crystal tuff appear corroded. Their boundaries are irregular with many deep smoothly curved embayments. These embayments are filled with microcrystalline material similar to the rest of the matrix. Similar corroded boundaries were also observed on a few albite phenoclasts. It is difficult to account for the observed morphologic differences. However, it is reasonable to assume that the grains have had very different histories. It seems probable the angular phenoclasts are intratelluric and the rounded and corroded are xenocysts.

Biotite phenoclasts are present in most samples but rarely exceed 5 percent of the rocks. All fragments show evidence of alteration ranging through various amounts of bleaching to oriented residues of hematite and leucoxene.

Point count analyses were made of regularly spaced samples taken from the crystal tuff in the core from the Tower diamond drill hole. These analyses by Harry D. Cowan showed a range of 7 to 46 percent feldspar phenoclasts and 0-10 percent quartz phenoclasts. Most of the samples contained 30 percent or more mineral phenoclasts, only those from the bottom 150 feet contain less.

Unusual fracture patterns have developed in most of the quartz and feldspar. The grains appear shattered and most of the fracturing terminates at the phenoclast boundaries, however in some sections the fracturing extends into the matrix (~~Fig.~~ ___). In general there has been little movement on these fractures, but separation has occured along some and the resulting space is filled with matrix material ~~(Fig. ___).~~

This shattering of the phenoclasts is probably related to the thermal history of the rock. Similar fracture patterns in other materials have been produced by contraction during rapid cooling, and this may be the origin of the shattering in the crystal tuff. .

The crystal tuff in the Chupaderas has been pervasively altered. This alteration varies in intensity from place to place, but in general increases upward from the base. There is no apparent systematic spacial relationship between the occurrences of manganese ore and the intensity of this alteration, even though it seems likely they are genetically related. As a result of the alteration most of the tuff is mottled light brown, light pink and pale greenish gray. Some of the feldspar phenoclasts megascopically appear cloudy others are chalky white depending on the intensity of the alteration. Many of the highly altered feldspar clasts, due to their soft friable character, are weathered out of surface exposures leaving small irregular shaped cavities.

The effects of alteration are conspicuous in thin sections. Most of the plageoclase, other than albite, has been completely altered to a fine mosiac of quartz, sericite and K-feldspar. This K-feldspar has been identified by Hewett (1946, p. 1453) as adularia. Much of the secondary K-feldspar is water-clear and the original orthoclase and sanadine show little evidence of alteration. Most of the albite, however, is highly altered, only a few clasts are unaffected. All of the albite is broken along closely spaced cleavage planes. Commonly the central areas between the intersecting cleavage planes are highly sericitized, but the areas adjacent to the breaks are unaffected. During thin sectioning the altered portions of some of these clasts are either plucked or washed away leaving a skeleton of unaltered albite. In other grains sericitization of the albite has progressed outward from the cleavage breaks in the usual way. The products of the alterations of the albite are extremely fine grained and probably contain minerals other than sericite; the presence of some K-feldspar seems likely. Stain tests indicate a high percent of potassium. As pointed out previously all the biotite shows varying degrees of alterations, ranging from simple bleaching to complete removal.

Because the groundmass of the tuff is fine grained the effects of alterations are not obvious. However, staining indicates the presence of a higher percentage of potassium than would normally be expected. Quartz has been introduced into the groundmass. It occurs in small druzy cavities and filling microfractures. A portion of the quartz disseminated through the groundmass may also have been introduced.

It is evident from the above descriptions that the crystal tuff has been completely permeated by a potassium rock solution and that the resulting alteration, although pervasive, is most intense in the upper layers. These observations suggest that the altering solutions were derived from the tuff itself and the alterations could be classed as deuteric or vapor phase effects. Similar conclusions have been reached concerning the alteration of the Bishop Tuff fumarolic mounds. M. F. Sheridan (1970 p. 864-865) concluded that the altering gases emitted from the Bishop Tuff fumaroles were derived from the tuff and were highly enriched in potassium and aluminum. He stated that the altered mound rocks were so strongly enriched in potassium that it was difficult to assign theoretical mineral phases.

The terms egnimbrite, welded tuff, ash flow, composit sheet, and cooling unit all have been informally used to describe the crystal tuff. Several and maybe all of these terms are applicable. However, the uncertainties surrounding the genesis of the crystal tuff are illustrated by the fact that an earlier report considered a large part of the unit to be intrusive.

The pyroclastic origin suggested here is based mainly on the presence of large amounts of fragmental mineral grains and on the abundance of large and small xenoliths. The presence of flow planes and possible eutaxitic structures also support the suggestion. R. L Smith (1960 p. 824) reports that elimination of all traces of shards even in the most highly welded tuff is seldom achieved. Questionable relict shards were observed in the crystal tuff, but are very rare. At places the distribution of outcrops clearly indicate the sheet-like nature of the crystal tuff. At other places it is inferred from the attitude of the stratification within the unit. At the Tower mine, where the tuff is most massive, its sheet-like character was verified by diamond drilling.

All the available evidence indicates a pyroclastic origin for the crystal tuff. However, the mechanics envolved in its accumulation are totally unknown and to use terms that suggest otherwise is unjustified.

### Andesite (Tba) and Associated Froth Breccia (Tfb)

These rocks cover an area along the northern ridges from highway U.S. 60 to Black Canyon and the Tower Mine. In the central parts of the mountains between Black Canyon and a point approximately one quarter of a mile south of Red Canyon they are absent. South of the central area the andesite is exposed at two places, one east of the Esperanza Mine on the east side of the Chupaderas and the other on the west slope of the mountains above Miera Tank. Andesite at one time probably covered much of the district, but since then large sections have been removed by erosion.

The andesite exposed in the area of Blue Canyon is interlayed with a volcanic breccia that to the west rests on andesite. All other remaining andesitic rocks in the Luis Lopez district lie directly on the crystal tuff. From this it is evident that there were at least two separate intervals of andesitic eruption. The andesite that rests directly on the crystal tuff in the northern part of the district differs texturally and structurally from andesite at the same stratigraphic position in the southern part of the district. The presence of more than one flow is also suggested by these differences. However, the evidence indicates that all the andesite was erupted immediately or shortly after the eruption of the crystal tuff, and therefore ~~are~~ is helpful stratigraphic markers.

The andesite flows range from massive through coarsely porphyritic to thinly flow banded. Exposures of the porphyritic andesite are restricted to the northern part of the area adjacent to highway U. S. 60 and along the ridge south of Box Canyon. At both places the porphyritic andesite is largely bounded by faults and as a result its relation to other rock units is obscured. Its dike-like appearance in the roadcut one mile east of Box Canyon on highway U. S. 60 is due to faulting. At the southwest end of this dike-like outcrop the porphyritic andesite is in normal contact with a valconic breccia containing clasts of the porphyritic andesite. Therefore it is assumed that here the porphyritic andesite was overlain by volcanic breccia.

In the western roadcut near Box Canyon porphyritic andesite is overlain by froth breccia. The same froth breccia overlies the massive andesite to the south. Inasmuch as the porphyritic and massive andesite occupy the same stratigraphic position, they may represent textural variations within a single flow.

Pitted weathered surfaces are characteristic of the porphyritic andesites. The pits were formed by weathering out of altered plagioclase phenocrysts, many of which were more than one centimeter long. The alteration of these feldspar phenocrysts is not related to processes of surface weathering, but apparently to the circulating potassium rich solutions that have, as previously noted, altered most of the extrussive rocks in the district. Recent exposures of the andesite in deep roadcuts show the same altered feldspar phenocrysts. Due to the alteration this andesite is variously bleached to shades of gray and light gray. Surface exposures are reddish brown or black due to iron stain.

X-ray diffraction analyses indicate the plagioclase phenocrysts are largely altered to aggregates of clay, sericite, and potassium feldspar, probably sanadine. In thin sections it is evident that the alterations proceeded first along the cleavage planes in the plagioclase. Adjacent to the cleavage the plagioclase is altered to a water-clear potassium feldspar, and the intervening areas are highly sericitized (Fig. 3)~~&)~~.

A few partially altered K-feldspar phenocrysts are present. The ferromagnesium minerals have been completely changed to a mixture of magnetite and hematite. The outlines of the original biotite and hornblende are still evident. The groundmass has a trachytic texture and the plagioclase laths are partially altered to a potassium rich aggregate as indicated by the development of a strong overall cobaltinitrite stain. Much secondary quartz is present in this phase of the andesite. The groundmass is cut by small veinlets of chalcedony and many of the small cavities are lined with irregularly oriented quartz crystals.

Massive andesite crops out in the Tower mine area and north along the central ridge from Black Canyon. It is also present in the area of Blue Canyon to the east and above Miera Tank on the southwest slope of the Chupaderas. It is the most widespread of the three types of extrusive andesite. The massive andesite is typically black, fine to medium grained, and locally propylitized. It is microporphyritic with phenocrysts of plagioclase, orthoclase, biotite and altered hornblende in a fine tr~~o~~achytic groundmass containing lath-shaped plagioclase. Alteration, other than propylitic, is less than in the rest of the eruptive rocks. The propylitic alteration is bright green somewhat similar to the color of the copper bearing mineral malachite. This similarity probably accounts for the short exploration tunnel in the altered upper part of the andesite on the east side of the large hogback east of the Tower mine. Secondary chalcedony and druzy quarts are present throughout

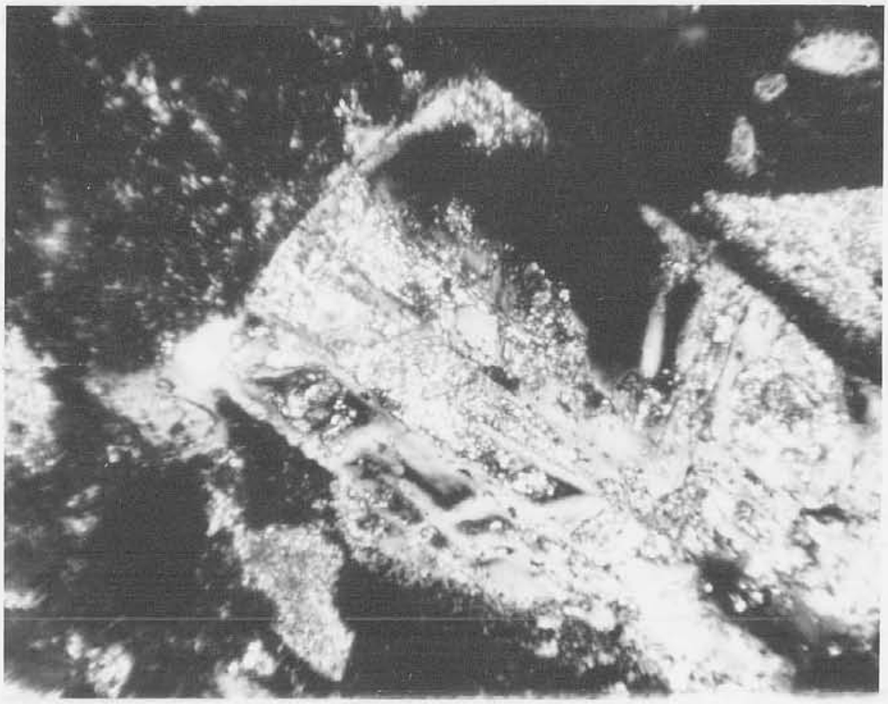


Fig.3: K-feldspar, sericite alterration along cleavage planes in plagioclase phenocryst from the porphyritic andesite. (X nichols, 40X)

following p 24

the andesite. Near the flow limits where the andesite is thin it is highly vesicular and the vesicules are lined with a green film of celadonite.

Banded andesite occurs over a fairly large area in the vicinity of the Esperanza and Black Crow-San Juan claims. It is also exposed in a small area at the Torres Mine a third of a mile south of Black Canyon on the west side of the mountain. At both places the andesite is aphanitic and laminated. The lamination is apparent due to slight textural variation and to color differences. Individual laminae range in thickness from a fraction of an inch to several inches. In general the layers are parallel to the base of the flow, flow-like folding was not observed. Most outcrops are varigated, the layers range in color through shades of gray, brown, and red. At places the rock tends to split along the laminae and the resulting talus is flaggy ~~(Fig. ___)~~.

The banded andesite is largely made up of plagioclase microlites that are flow oriented and parallel to the megascopic banding. It contains scattered small phenocrysts of partly altered pyroxene, probably enstatite, and small grains of olivene with thin reaction rims. Angular clasts of quartz and oligoclase are common. Tiny quartz veinlets are numerous and many fractures and small cavities are filled with calcite. At the Torres Mine parts of this andesite are thoroughly silicified. The only known occurrences of manganese mineralization in andesite are in the brecciated banded andesite at the Torres and Black Crow-San Juan pits.

## Froth Breccia (Tfb)

Exposures of froth breccia are limited to the northern third of the mapped area. It is well exposed at the north end of Box Canyon near highway U. S. 60. Exposures continue from there south to Black Canyon. The exposures in the northern two thirds of the area are largely in fault contact with the other rocks. The remaining outcrops to the south are in normal contact with the massive andesite and volcanic breccia. Approximately a half mile north of Black Canyon the froth breccia occurs both above and below the massive andesite; to the east this froth breccia is overlain by rhyolitic volcanic breccia. At the west end of the Black Canyon "box" it is exposed below the andesite.

Just south of highway U. S. 60, the upper froth breccia is roughly 200 feet thick. The outcrop pattern suggest that its thickness varies irregularly and rapidly from place to place. One quarter of a mile north of the Black Canyon "box" approximately 120 feet of froth breccia are exposed below the andesite. The base of this lower froth breccia is not exposed in the map area and therefore its total thickness is unknown. The froth breccia is not present at the surface in the Tower Mine area and was not encountered in the diamond drill hole.

The froth breccia is a completely vesiculated mass containing many small and large xenoclasts of the earlier volcanic rocks; crystal tuff fragments are most abundant. Xenoclasts of several Precambrian rock types are also common, and small clasts of quartz, sanadine, and oligoclase are scattered in the matrix. The froth breccia is everywhere well stratified, individual layers are commonly 10 to 20 feet thick. Each of the layers probably is a separate flow unit. Contacts between layers and between the froth breccia and the massive andesite are sharp. The vesiculated matrix of the breccia is highly altered to a tan or light gray. Some of the vesicules are filled with clay-like material. The vesicular matrix is completely divitrified and contains altered plagioclase laths that are now a mixture of potassium feldspar and sericite. These laths are flow oriented, but as would be expected, the flow pattern is complex. All the ferromagnesium minerals have been altered to a light brown cryptocrystalline material. The outlines of many of these altered minerals are still recognizable. The alteration plus the abundant xenoclasts of both crystals and lithics make it difficult to determine the composition of the original froth.

Although the evidence is not compelling it does seem likely that the andesite and froth breccia flow units are genetically related and parts of a composit sheet. The abundant xenoclasts in the rock froth and their general absence in ~~a~~ the closely associated andesite suggests a period of relatively violent gaseous eruption that for a short time was interrupted by a qui~~ck~~et outpouring of andesitic lava.

### Volcanic Breccia (Tvb)

Physical variations within the volcanic breccia are numerous, and the several varities interfinger and are gradational into each other. At places this unit appears to grade into a flow breccia at the top of the andesite. A similar gradation occurs where the underlying rock is froth breccia. Both the volcanic breccia and the froth breccia appear to be late stage products of the andesitic period of eruption.

All phases of the volcanic breccia are heterolithic and made up largely of clast from earlier eruptive rocks. Nonvolcanic clasts are rare and consist largely of granitic gneiss and schists. Flow banded rhyolite, crystal tuff and andesite fragments predominate, and the ratio of these changes rapidly both horizontally and vertically. A few exposures south of highway U. S. 60 at the east edge of the Chupaderas contain only flow banded rhyolite. In general there appears to be an upward increase in the ratio of rhyolite to andesite. On the map, those parts of the volcanic breccia that contain conspicuous amounts of andesite have been separated from the more rhyolitic parts.

Stratification is well developed in some outcrops and absent in others. Individual beds range from a few inches to several feet thick. In general the beds thicken upward in the section. Clasts, as would be expected, are largest in the thicker beds. Xenoclasts a foot or more across are common and sorting is generally poor. In some outcrops adjacent xenoclasts can be fitted together along a common fracture surface. Evidently the fracturing of these xenoclasts occurred during deposition, for the space between the fragments, usually less than one inch, is filled with the same matrix material as is present in the rest of the breccia.

The matrix is characteristically brick red, finely granular, and commonly vesicular in appearance. It consists of small fragments of quartz, K-feldspar, and plumose devitrified glass; in a microcrystalline to gl~~o~~assy matrix. A flow structure is developed in the matrix and commonly wraps around the larger mineral grains. Many of the mineral grains are surrounded by a glass in which microscopic spherulites have developed. Relict shards were observed in the matrix in some thin sections. The percent matrix in the volcanic breccia changes from place to place. In some exposures it makes up as much as 50 percent of the rock. A fusion analyses of the matrix by Miesch (1956) indicated a silica content of 62±2 percent and from this he concluded that the matrix probably was latitic in composition.

Characteristically the volcanic breccia is a resistant unit and as a result is commonly exposed in steep cliffs. When broken it tends to fracture through the clasts. East of the mine road approximately three quarters of a mile north of the Tower pit the upper rhyolitic parts of the breccia appear to be partly welded. Exposures along the east side of the Chupaderas south of highway U. S. 60 and in the central area between Blue Canyon and Black Canyon are highly silicified. Much of this silicification is spacially related to mapped faults.

The exact position of the volcanic breccia in the Tertiary stratigraphy of the Chupaderas is not established. However, it did accumulate after the andesite and froth breccia and locally it may overlie either of these. In the area of the Tower Mine the andesite is overlain by the tuff breccia ~~and~~ which is in turn overlain by the welded crystal rich tuff ~~—tuff breccia~~. At the Tower these units occupy the same stratigraphic position as the volcanic breccia does elsewhere. Neither of these units was observed in contact with the volcanic breccia. Hence, their relative ages cannot be established. The tuff breccia and volcanic breccia may have accumulated at the same time, ~~but~~ However, the observed gradational contacts between andesite, froth breccia, and volcanic breccia; the suggested latitic composition of the volcanic breccia matrix; and the lack of tuff breccia xenoclasts in the ~~volcanic breccia suggest a clase genetic relationship with~~ that the volcanic breccia and the andesite are genetically related and accumulation prior to the eruption of the tuff breccia. ~~eruption.~~

A thickness of approximately 400 feet of volcanic breccia remains in the district. Its original thickness is unknown, everywhere its upper surface has been eroded. Exposures of volcanic breccia are limited to the northern and west central parts of the district. The original distribution of the breccia cannot be determined, but field relations suggest it probably was not widespread.

Volcanic breccia is defined as a more or less indurated pyroclastic rock consisting chiefly of accessory and ~~o~~accidental angular ejecta in a fine tuff matrix, and the definition is applicable to the breccia in the Chupaderas. Several processes may have been involved in the transportation and deposition of these breccia, but because of the limited available data the nature of these processes could not be established. Processes similar to those envolved in the formation of ash flows might be invoked. However, it should be pointed out that there still is some confusion concerning the exact nature of these processes. A part of the volcanic breccia, as has been informally suggested, may be a laher; that is, a flood of water saturated volcanic debris that moved down the slope of a volcano in response to gravitative forces. Generally ancient mud flows and landslides of volcanic debris are difficult to distinguish from pyroclastic deposits of other origins, and in the Chupaderas the available data is inadequate.

## Tuff Breccia (Ttb)

This unit is exposed in two areas, one in the northern part of the district near the Tower and Gloryana mines and the other in the southeast corner of the district approximately a mile south of the MCA pits. The rocks in these areas are not exactly comparable, but they occur at the same stratigraphic position and therefore are considered equivalent. At the Tower mine the tuff rests on a vesicular phase of the andesite and is overlain by a highly welded crystal rich tuff, megascopically similar to the crystal tuff below the andesite. In the southeast area the tuff overlies a massive phase of the andesite; the overlying rock has been eroded. This tuff is widespread in areas to the south of the mapped area. Its former extent to the north within the mapped area cannot be determined, but it probably did not join with the tuff exposed near the Tower and Gloryana mines. This is suggested by the fact that the welded crystal rich tuff that overlies the tuff breccia in the Tower area rests directly on the andesite at the Torres mine, approximately halfway between the two areas.

As was stated the tuff breccia in the two areas are not exactly comparable. In the northern exposures the rock is very light gray, porous, and contains abundant xenoclasts, several inches across, of the underlying vesicular andesite (Fig. 4). The rock is stratified and the proportions of xenoliths to matrix decreases upward. Scattered fragments of pumice-like material in the tuff are made up of loosely packed bundles of parallel rod shaped aggregates of anhedral sanadine and quartz (Fig. 5). These minerals are arranged in a radial pattern normal to the long axes of the rods. In some of the fragments the space between rods is filled with coarsely crystalline calcite, and as a result appear much like recrystalized gray limestone. Their outer contacts are sharply angular, and they

Fig. 4: Tuff Breccia (Ttb) at the Gloryana pit. Large clasts are vesicular basalt.

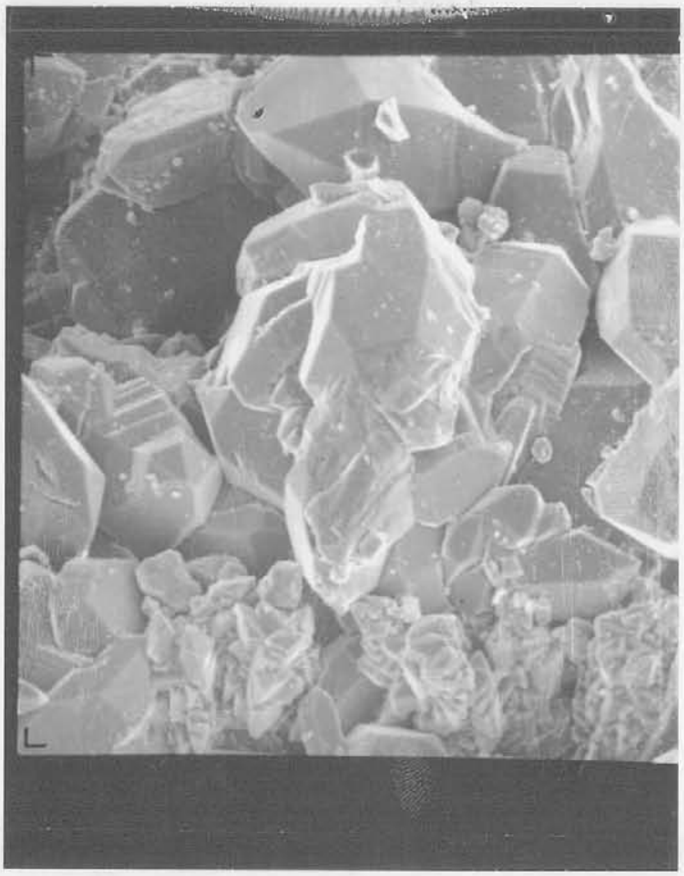


Fig. 5: SEM photo of quartz and sanidene in alterred limestone (?)xenoclasts from from the tuff breccia (Ttb) (260X)

following page 30

range in size from a fraction of an inch to several inches. The orientation of the quartz-sanadine rods, with respect to the whole rock, is different in each xenolith. The original clasts may have been limestone. If so, the limestone was initially partly replaced by quartz and sanadine, and subsequently the remaining calcite was removed. The alteration of these clasts probably was accomplished by the same hydrothermal solutions that produced the pervasive alteration noted in the other rock of the district.

The ashy matrix of the tuff breccia in the Tower-Gloryana area is devitrified and consists largely of microcrystalline quartz and K-feldspar. The presence of K-feldspar is suggested by the strong potassium stain obtained with cobaltinitrite. The shard structure is still clearly evident and small spherulites are common. Phenoclasts of quartz, sanadine, and albite are scattered throughout. There is little or no plagioclase and the rock is only slightly welded. Approximately 100 feet of tuff breccia is exposed in this northern area.

The tuff in the southeast area is divided into two parts by a diabase sill. The portion below the diabase is 20 to 40 feet thick and very similar to the rock at the Tower and Gloryana mines. Above the diabase it is tan to light gray, dense, and moderately welded, with sparse phenoclasts of feldspar biotite, and hornblende. Oligoclase is the principal feldspar, and most of it is unaltered. There are few quartz phenoclasts. Altered euhedral sphene is scattered through parts of the rock. Xenoliths one inch or less across of massive andesite are abundant. The groundmass is devitrified and highly altered to a clay-like material, probably kaolinite. Large and small areas of plumose microlites are common. Most of the shard structure has been obliterated. The lower 5 to 6 feet above the diabase are of mottled black and light brown glass. This glass contains the same mineral phenoclasts as the overlying tuff. The brown areas are due to progressing devitrification, and consist of spherulites and plumose microlite aggregates.

The tuff breccia near the Tower and Gloryana mines and the tuff breccia in the southeast part of the mapped area occupy the same stratigraphic position. However, the observed physical and mineralogic differences are sufficient to suggest that they had different histories, and are parts of separate ash flows.

## Welded Crystal Rich Tuff (Twx)

Overlying the tuff breccia in the Tower mine area and resting directly on the andesite at the Torres mine are outcrops of a welded crystal rich tuff. At both places its upper surface has been eroded and the maximum remaining thickness is approximately 100 feet. Large residual boulders, several feet across, of this rock are present at the crest of the andesite hill north of the road to the Black Crow-San Juan pits, in the northeast corner of the mapped area. Hence, it appears that this unit may have once covered most of the area.

Near its base, west of the Tower pit, this unit is a coarse volcanic breccia containing angular to subrounded fragments 2 to 3 feet across of flow banded rhyolite and crystal tuff set in a dense, aphanitic, dark red matrix. This basal part appears to grade into the underlying tuff breccia. The number of large fragments decreases upward and near the top the unit is a dense, red, highly welded crystal rich tuff very similar in appearance to the massive crystal tuff below the andesite.

North-northwest of the Optimo mine the unit is in part coarsely flow banded and it is difficult to determine whether these parts are welded tuff or flow rhyolite. In these pink to gray flow banded rocks are zones containing large angular rhyolite fragments 2 to 3 feet across that appear to be flow breccia. Much of the rock in this area is highly altered, and due to weathering most outcrops are cavernous.

The welded crystal rich tuff in the northern half of the area rests on the tuff breccia, which in turn rests on the andesite. In the central area, at the Torres mine the crystal rich tuff rests directly on andesite. In the southern part of the area the welded tuff breccia and associated rhyolitic glass overlie the andesite. All these rock types occur at the same stratigraphic position and all are rhyolitic. They differ only in lithology and it therefore appears likely that they are related parts of a once widespread composit sheet.

## Intrusive Rocks

Large intrusives of igneous rock are not exposed in the district, but numerous small dikes and sills occur throughout the area. These small intrusives range in composition from basic to intermediate; including olivene rich diabase, andesite, and latite. These compositional types were not observed cross-cutting each other, but their relative ages are indicated by their distribution with respect to other rocks in the district. Dikes and sills of andesite and latite occur only in earlier volcanic rocks, none was observed cutting the overlying Tertiary-Quaternary sediments. Olivene rich diabase occurs mainly as thin sills and only in the late playa silts and clays of the Popotosa (?) formations. This diabase is probably the time equivalent of the basalt flow that caps Black Mesa north of highway U. S. 60.

Dikes and intrusive plugs of andesite are numerous in the southern half of the area, and generally are in recognized north-northwest trending faults. One exception, north of Black Canyon, is in the east-northeast trending fault that passes between the Tower and Gloryana mines. This dike is approximately 5 feet across and intrudes the andesite flow and overlying volcanic breccia. These rocks are near the top of the volcanic section.

The andesite plug in the southeast corner of the area is at the junction of two cross-cutting faults. The attached dike that extends north from the plug follows the trace of a major fault. The average thickness of the dike is approximately 50 feet, but at its intersection with the east-northeast fault south of the MCA pit it is roughly 200 feet thick. The andesite at the south end of the dike has a well developed ophitic texture, north this texture disappears and the rock is aphanitic with only scattered plagioclase phenocrysts. At several places west of the MCA pits the dike rock is vesicular, has been brecciated and recemented by andesite. As a result it has the appearance of a flow breccia. These observations suggest that intrusion and fault movement, were in part contemporaneous. Several outcrops of the andesite dikes that cross Red Canyon near its west end were interpreted by Miesch (1956) as very large xenoliths. However, their linear arrangement parallel to the north-northwest fault pattern plus the fact that they are lithologically similar to the other dike rocks make this unlikely.

The exposed andesite west of the major north trending fault in the southeast corner of the area is probably a sill, none of the usual texture and structures associated with surface flows is present. This probable sill is in the welded tuff breccia that overlies the main andesite flow. The andesite in the sill is ophitic like the adjacent andesite plug and dike, but is somewhat lighter colored. It is largely a felted mass of very small plagioclase crystals surrounding 1 to 2 mm. long laths of andesine, hornblende, and augite. The central parts of many of the andesine phenocrysts are altered to a clay-like material, and most of the hornblende is surrounded by alteration rims of hematite. The augite is unaltered.

Latite dikes occur in the ridge east of Big Basin and west and south of Red Canyon. All these dikes, like the andesite dikes, occur along recognized faults. However, the latite dikes are largely restricted to the east-northeast faults and hence are approximately at right angles to the trend of the andesite dikes. Latite dikes in the Big Basin area are 45 to 65 feet across, are light brown to light gray, dense aphanitic, and contain widely scattered small phenocrysts that are completely altered to a clay-like material. These phenocryst originally may have been plagioclase. In addition the rock contains microphenocrysts of orthoclase and biotite set in a microcrystalline matrix of plagioclase, quartz, and disseminated flakes of hematite. The hematite flakes appear to be pseudomorphic after biotite. The color of the rock is largely due to the presence of this disseminated hematite. In this outcrop there is a weak flow banding that is oriented parallel to the walls of the dikes. This flow structure is not evident in thin sections.

Near the west end of Red Canyon highly p~~a~~orphyritic pink to light gray latite intrudes the crystal tuff and the main andesite flow. These intrusives are aligned along two known faults, one of which trends east-west, the other northwest. At the surface these intrusives appear as a series of small elongate plugs. The largest occurs at the projected intersection of the controlling faults, and is approximately 1300 feet long and 500 feet wide. The latite in these intrusives characteristically contain phenocrysts of sanadine up to one-half an inch across. Smaller crystals of plagioclase ~~is~~ are zoned from andesine to oligaclase and the central parts of the crystals are altered to a clay-like mass. Sanadine and biotite are unaltered.

Quartz grains a few millimeters across are common. All these grains are highly rounded and many are almost spherical, others are deeply embayed (Fig. 6 ). A thin rim of microcrystalline material has developed around some of these grains, and the surface of many appear cra~~gg~~zed. The microfractures that produce this appearance are limited to a thin layer at the surface of the grain (Fig. 7 ). The above observations suggest that the relatively large quartz grains are xenocrysts. The embayments suggest the quartz was unstable, and hence was partially dissolved in the latite magma. The microfractures, as in ceramics, may have resulted from thermal shock. The relation of these fractures to the surface of the rounded grains further suggests that the grains were

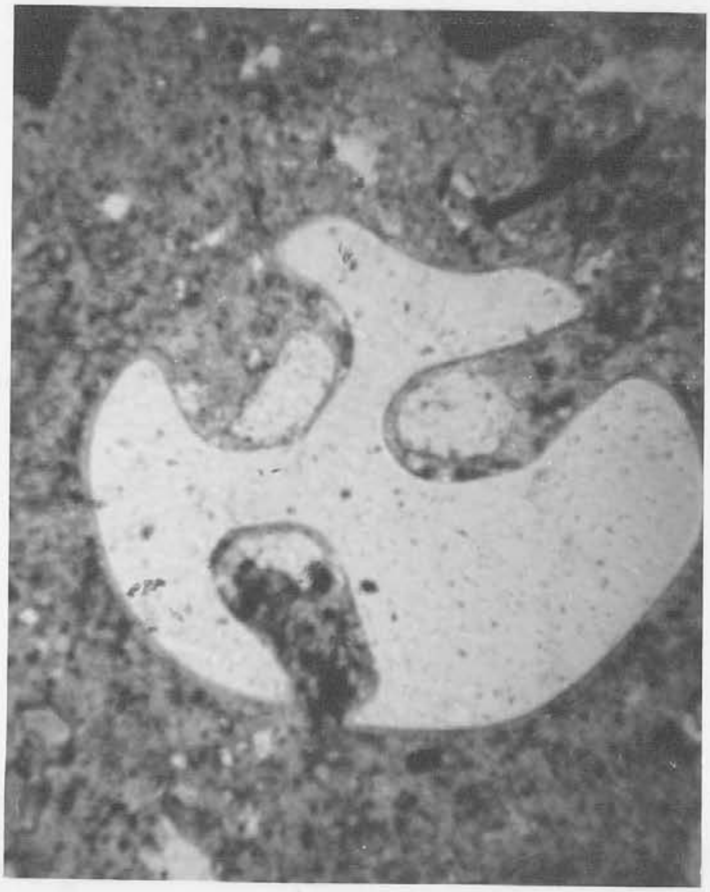


Fig. 6: Rounded and deeply embayed quartz grain from the Red Canyon latite intrusive. ( ? X)

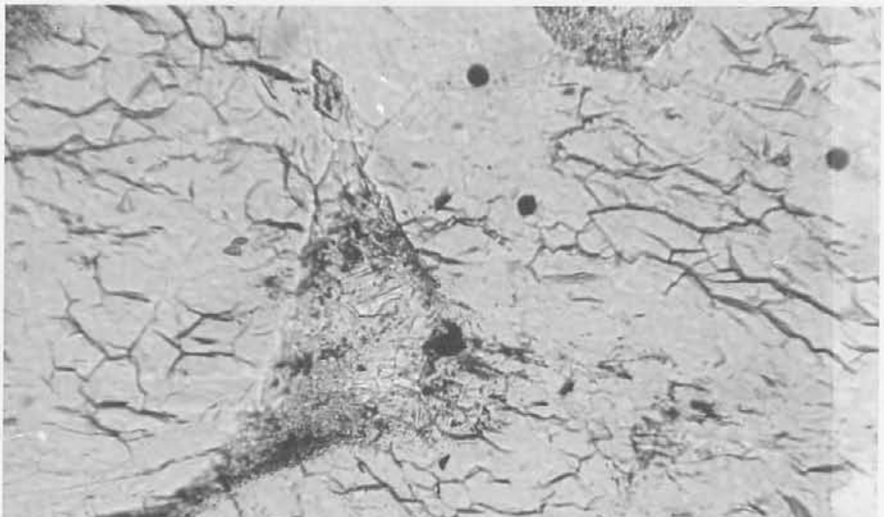


Fig 7: Microfractures in quartz grains from Red Canyon latite intrusive. ( ?X)

foll. p 35

at least partially rounded before being incorporated in the latite. Hence, their immediate source may have been as sedimentary rock. A few feldspar grains have similar characteristics and probably have had the same history.

Diabase dikes and sills in the playa silts and clays of the Popotosa formation are clearly the youngest intrusives in the district. These diabase intrusives are well exposed south of highway U. S. 60 and along the west side of the mountains. The diabase in all exposures is black to greenish-black, holocrystalline and composed largely of labradorite, augite, olivene and scattered magnetite. Much of the olivene is euhedral and surrounded by reaction rims. The augite is anhedral and occurs in the irregular spaces between randomly oriented laths of labradorite.

## K-Ar Age of the Volcanic Rocks

On the basis of physical characteristics the volcanic rocks of the Chupadera Mountains have been tentatively correlated with units of the Datil Group. The crystal tuff of the Luis Lopez area is closely comparable with a large part of the Hells Mesa member of the Datil Group in the Bear Mountains 25 miles to the northwest and a tuff presumed to be equivalent of the Hells Mesa in Six Mile Canyon on the east flank of the Magdalena Mountains four miles to the west. Neither of these exposures is traceable into the Chupaderas or into each other. Correlations of this type based largely on composition and lithology are questionable, even over these short distances. Hence, four K-Ar age determinations were made to test the earlier tentative correlations.

The new K-Ar age determinations reported here were made for the New Mexico Bureau of Mines, by Geochron Laboratories, Inc. All samples were collected by the author during the investigation of the Luis Lopez manganese district.

The K-Ar age of the Hells Mesa in the Bear Mountains, as reported by Weber (1971, p. 37) is 30.6 ± 2.8 million years. The K-Ar age of the crystal rich, welded, rhyolitic tuff from Six Mile Canyon in the Magdalenas, as determined during this study, is 22.5 ± 0.9 million years. The [illegible] crystal tuff in the Luis Lopez district is 15.0 ± 0.6 million years. The K-Ar age of the glass near the base of the tuff breccia in the southeast corner of the mapped area was determined to be 22.2 ± 0.9 million years. This glass overlies and is separated from the crystal tuff (15.0 m.y.) by an andesite flow. Clearly, this determination is not in agreement with the field data. The coarsely porphyritic Red Canyon latite dike that cuts the crystal tuff (15.0 m.y.) gave a K-Ar age of 11.7 ± 0.6 million years; this determination is consistant with the geologic field relations.

On the basis of these determinations, two conclusions appear possible. One, it may be assumed that the K-Ar ages are correct and that the principal host rock for the manganese mineralization in the Luis Lopez district is much younger than the rocks at the other two localities. If the conclusion is accepted it must be assumed that the age of the rhyolitic glass (22.2 m.y.) above the crystal tuff (15.0 m.y.) is anomalic due to retention of extraneous argon after extrusion. It also follows that the observed widespread alterations in these rocks did not effect the age determinations and therefore probably was deuteric. Field relations suggest that the general alterations and the ore mineralization are syngenetic.

An alternative explanation, equally acceptable on the basis of the data thus far presented, assumes the rocks on Hells Mesa, in Six Mile Canyon, and the Chupaderas are correlative and that in the Chupaderas the K-Ar clock was reset. This resetting must have occured during a post-extrusion period of hydrothermal activity. The pervasive alterations and the ore mineralization are considered to be products of this period. It therefore follows that the ore mineralization is younger than the host rock by approximately 15 million years and that the hydrothermal fluids were derived from some subjacent source not directly related to the volcanism.

Both the above interpretations are plausible and both may be effectively used to account for various aspects of the local and regional geology. To the writer, however, it seems probable that the volcanic rocks in the Luis Lopez district are younger than the Datil Group. This choice, as will be seen, is based largely on the relationship between the regional alteration, the ore mineralization, the structures, and the host rocks.

## Tertiary-Quaternary Sedimentary Deposits

### Popotosa (?) Formation (TQp)

The Popotosa formation was defined by C. S. Denny (1940) as representing the transition between the principal epoch of volcanic activity (Miocene (?)) and the period of deposition of the Santa Fe formation (Pliocene). In the type area, as described by Denny, the Popotosa consists predominately of fine grained sand and diversely colored silty-clay conformably overlain by pebble to boulder conglomerate. This conglomerate is composed largely of various types of volcanic rock and minor amounts of granite, schist, quartzite, and sandstone. These beds rest unconformably on the Tertiary volcanics and are overlain by the Santa Fe formation. Denny estimated an original thickness of 3000 to 5000 feet for the Popotosa in the San Acacia area.

Similar sedimentary deposits are widespread in the lowlands surrounding the mapped parts of the Chupadera Mountains, and in adjacent areas to the north. These sediments, as in the type area, are unconformable on the Tertiary volcanics. However, the Santa Fe formation which is present in the type area is missing and the deposits are overlain by a thin veneer of pediment gravel. The sediments surrounding the Chupaderas have not been carefully traced into the type area west of San Acacia, but it seems likely they are part of the Popotosa formation, and hence will be referred to as Popotosa (?) in the remainder of this report.

The lower parts of the Popotosa (?) are very fine sand or silty-clay, and characteristically laminated. Laminae range in color from shades of light gray, blue-gray, lavender, green, and brick red. All exposures contain abundant secondary vienlets of selenite, many an inch or more thick. This gypsum probably was deposited with the sediments, but since has been transported and redeposited by ground water. This lower unit of the Popotosa (?) contains abundant montmorillonoid clay, and has been used locally to seal stock ponds and irrigation ditches. Thus far, attempts to use it in drilling mud have been unsuccessful. In water these clays slake quickly but there is little swelling. Benzidine dihydrochloride tests give a positive montmorillonite reaction, and their differential thermal curves are similar to standard montmorillonite curves. Their x-ray diffraction charts are not well defined, suggesting the material is poorly crystalline and/or extremely fine grained.

A complete section of the silty-clay part of the Popotosa (?) is not exposed in the Luis Lopez district. Roughly 100 to 200 feet are exposed in the arroyos along the west side of the Chupadera Mountains. On Black Mesa north of highway U. S. 60 near the north end of the mapped area another 400 to 500 feet are exposed. These exposures on Black Mesa are topographically above those west of the Chupaderas and therefore higher stratigraphically. Hence, from 500 to 700 feet of the clayey beds are exposed.

Two small exposures, not shown on the map, were observed east of the mountains; one at Chupadera Spring just south of highway U.S. 60

and the other near the stock pond in Big Basin. Chupadera Spring is at the contact between the clay beds and an overlying pebble-cobble conglomerate. This contact is near the bottom of an arroyo approximately 100 feet below the general level of the surrounding area, and roughly 700 feet lower than the surface exposures west of the mountains. This difference in elevation must be due to a structural offset that predates the Chupadera uplift (Fig. 8**). The silty-clays exposed in Big Basin and in the low areas west of Box Canyon, shown on the map, are erosional remnants within structural lows in the Chupaderas, and hence it is evident that the Popotosa (?) was once continuous across the area.

The lower clay unit of the Popotosa (?) probably was deposited in a playa in the central area of an enclosed desert basin. Playa deposits characteristically are uniformly fine-grained, regularly laminated, show a diversity of colors, and contain an abundance of gypsum. All of these features are typical of the lower parts of the Popotosa (?). The presence of a large amount of montmorillonite in these beds is also consistant with the above interpretation. Montmorillonite commonly forms from the alteration of volcanic ash in an alkaline environment. A large part of the Popotosa (?) was derived from volcanic rock and in a playa environment would alter to montmorillonite. Much of the original volcanic ash in the playa was mixed with other fine sediment at the time of deposition and therefore, probably was transported by water. However, some of the purest montmorillonite beds may have originated from direct ash falls.

---

** in pocket

The upper conglomeratic phases of the Popotosa (?) are alluvial fan deposits that once bordered the playa in which the silty-clays were deposited. Characteristically fan deposits gradually become finer grained both vertically and horizontally as filling of the basin of deposition progresses. Hence in the mapped area, the abrupt, vertical change from fine playa sediments to coarse conglomerate is atypical and is interpreted as due to a marked increase in the topographic relief of the basin area during deposition. A similar explanation was proposed by Denny (1940) for a similar abrupt textural change in the Popotosa sediments of the San Acacia area.

The gently east sloping erosion surface of low relief along the east and west sides of the Chupadera Mountains is developed largely on the Popotosa (?) formation. In general the surface west of the Chupaderas is on the lower playa deposits. East of the mountains it is on the upper conglomerate. The series of rounded hills and ridges that stand approximately 200 feet above the erosion surface on the west side of the mountains, roughly opposit Red Canyon, are erosional remnants of the upper conglomerate. The small hill north of the road out of Big Basin on the east side of the mountains also stands above this surface and similarly is a residual of the old topography left by the erosion that produced the surrounding plain.

Where exposed the upper unit of the Popotosa (?) consists of beds of medium to coarse conglomerate cemented by calcite with interlayed sand and sandy-silt beds. Although exposures are not adequate, it appears that this part of the formation becomes finer grained to the east. The beds in the upper unit and the laminae in the lower clays dip north-east. Inasmuch as the playa silty-clays were layed down essentially horizontal the present dip of from 6 to 10 degrees must be due to structural tilting. The gentle east sloping erosion surface developed on the Popotosa (?) and the dip of the Popotosa (?) beds are discordant. Hence, the erosion surface formed after the tilting and it is interpreted as part of a pediment that lies at the foot of the Magdalena Mountains. Due to base level changes the pediment is dissected by numerous arroyos, most of which drain to the east.

## Pediment Gravel (QTp)

The pediment surface, whether it is on the playa muds or the fan conglomerates of the Popotosa (?), is veneered by several feet of coarse gravel. In part, this gravel was derived from the conglomeratic phase of the Popotosa (?), but west of the Chupaderas it largely originated from talus off the Magdalena Mountains. The talus in this area is mainly of gray to reddish-brown welded crystal tuff that has a well developed eutaxitic structure. It is very similar to the crystal tuff in the mapped area.

## Landslide (Ql)

The lower silty-clays of the Popotosa (?) are very unstable on steep slopes. This is due largely to the high percentage of montmorillanite they contain. As a result of this instability landslides are common where the silty-clay is at or near the surface. Large areas of landslides occur on the slopes of Black Mesa north of highway U. S. 60. A small part of these slides extend into the mapped area.

### Alluvium (Qal)

The alluvium, as mapped, includes stream channel flood plains, and stream terrace sands and gravels. Much of the surface in the Chupaderas is covered by a thin mantle of loose rock debris. Where this regolith is thick, as on the lower hill slopes, it also has been mapped with the alluvium.

## Structural Geology

### Introduction

The Chupadera Mountains are a structurally elevated and complexly faulted block of Tertiary volcanic rocks within the Rio Grande depression. Structurally and topographically they are a southern extension of the Socorro, Lemitar Polvadera mountains intravalley highland. They are bordered on the east by the terraces of the Rio Grande Valley and on the west by a southern extension of the Snake Ranch Flats. West of this part of the flats is the high eastern scarp of the Magdalena Mountains. Within the Chupadera horst are several divergent fracture systems that have little apparent systematic relationship. Displacements on these fractures are generally of the order of a few hundred feet at most. Individual fault blocks are tilted, some as much as forty degrees.

The Popotosa (?) formation is envolved in the faulting and at one place the pediment gravels appear to be offset ~~(Fig.~~ ). At present the area is seismically active (Sanford 1965). Evidently tectonic adjustments are still occurring.

Brecciation and closely spaced jointing are widespread and especially evident in the crystal tuff ~~(?)~~. These structures at places are clearly related to faulting, at other places this relationship is not evident. In some exposures the breccia fragments are randomly oriented and obviously have been moved about (Fig. 9, a). In others the movement of fragments has been slight (Fig. 9, b). The principal ore bodies are localized in the areas of most intense brecciation and faulting.

Structural Boundaries

The structural and topographic boundaries of the Chupadera horst roughly coincide. The east and west boundaries consist of a series of en echelon north-northwest trending faults rather than single continuous fractures (Plate-I). On the east the location and trend of these faults are marked by well defined scarps and are confined to a zone approximately one half mile wide. On the west the boundary is less well defined and the faults are spread through a much wider zone. On the west there is one well developed scarp near the north end of the Chupaderas opposit the Tower Mine (Fig. 10). The main boundary fault

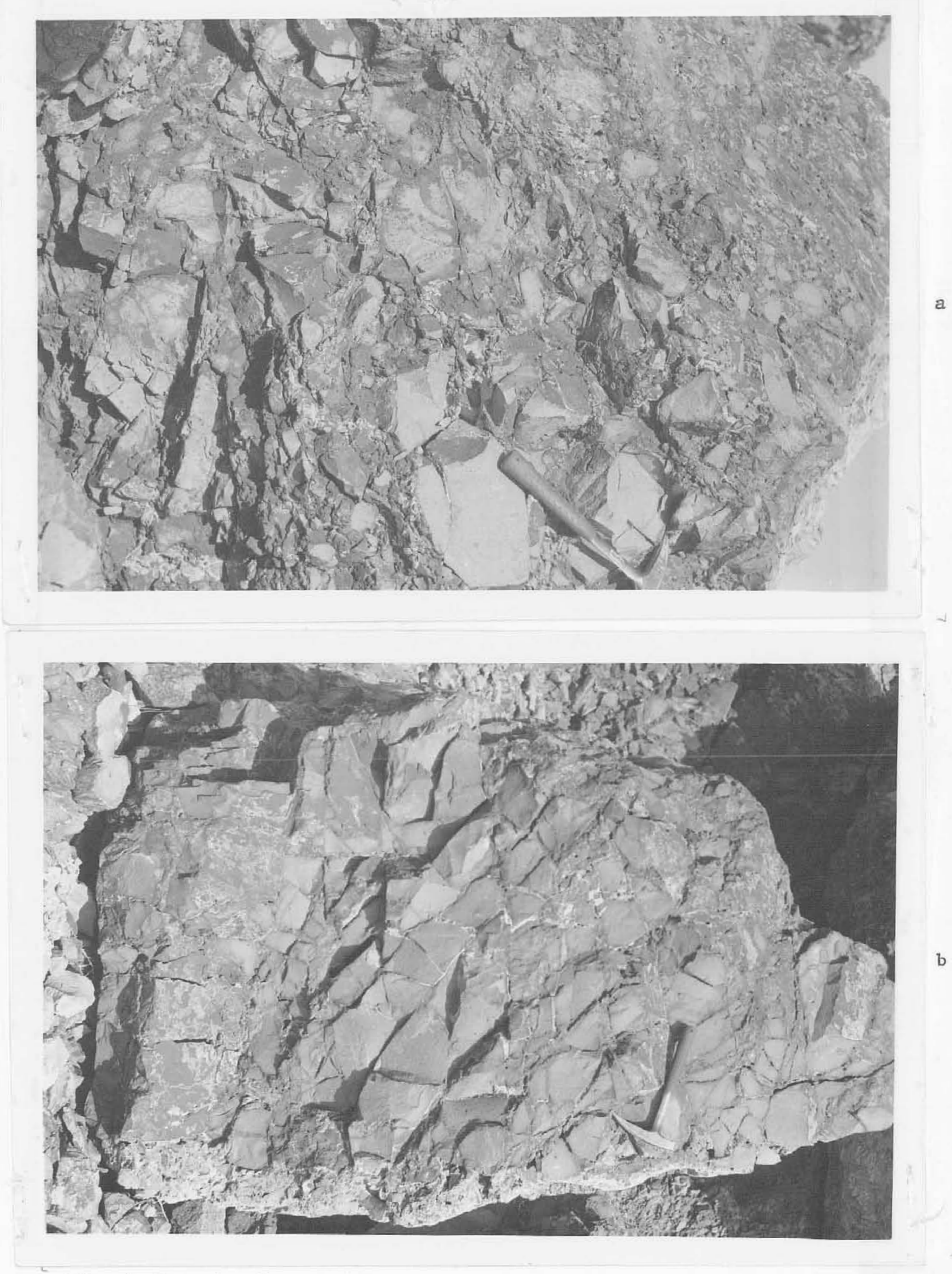


Fig. 9: Brecciated crystal tuff exposed in the MCA pit; a): breccia fragments have been moved about, and are randomly oriented. b) the rock is shattered but the fragments are only slightly displaced.

following p 45

OFR166

Fig. 10: Scarp of the western boundary fault at the north end of the Chupadera Mountains.

following p45

south of this has no topographic expression and is recognized only by stratigraphic separation. West of ~~this~~ the boundary fault are the coarse upper gravels of the Popotosa (?), and to the east are the tilted layers of the volcanic breccia (~~Fig.~~ Photo - 1). The mountain front in this area is a fault line scarp.

Most of the faults in the boundary zones are high angle faults; dips range from vertical to 75 degrees either east or west. The last movement as indicated by slickensides, observed at a few places, has been largely vertical. Only the minor cross fractures in these zones show evidence of strike slip movement.

## Structure Within the Horst

The elevated block is cut by a large number of variously trending high angle faults. Many of the major faults are roughly parallel to the north-northwest trend of the boundary zones, others are oriented approximately east-west, and between these major breaks are a number of randomly oriented minor faults (Fig. 11). As a result, the main Chupadera horst is made up of a mosaic of small fault bounded blocks. The number of these small fault blocks shown on the map is probably only a part of the total number present. Only those that show stratigraphic separation could be mapped, and it seems likely that many were unobserved in the large area of crystall tuff in the south central part of the area. Many of the andesite and latite dikes in this area are along recognized faults and others are assumed to be although actual displacement in the country rock could not be established.

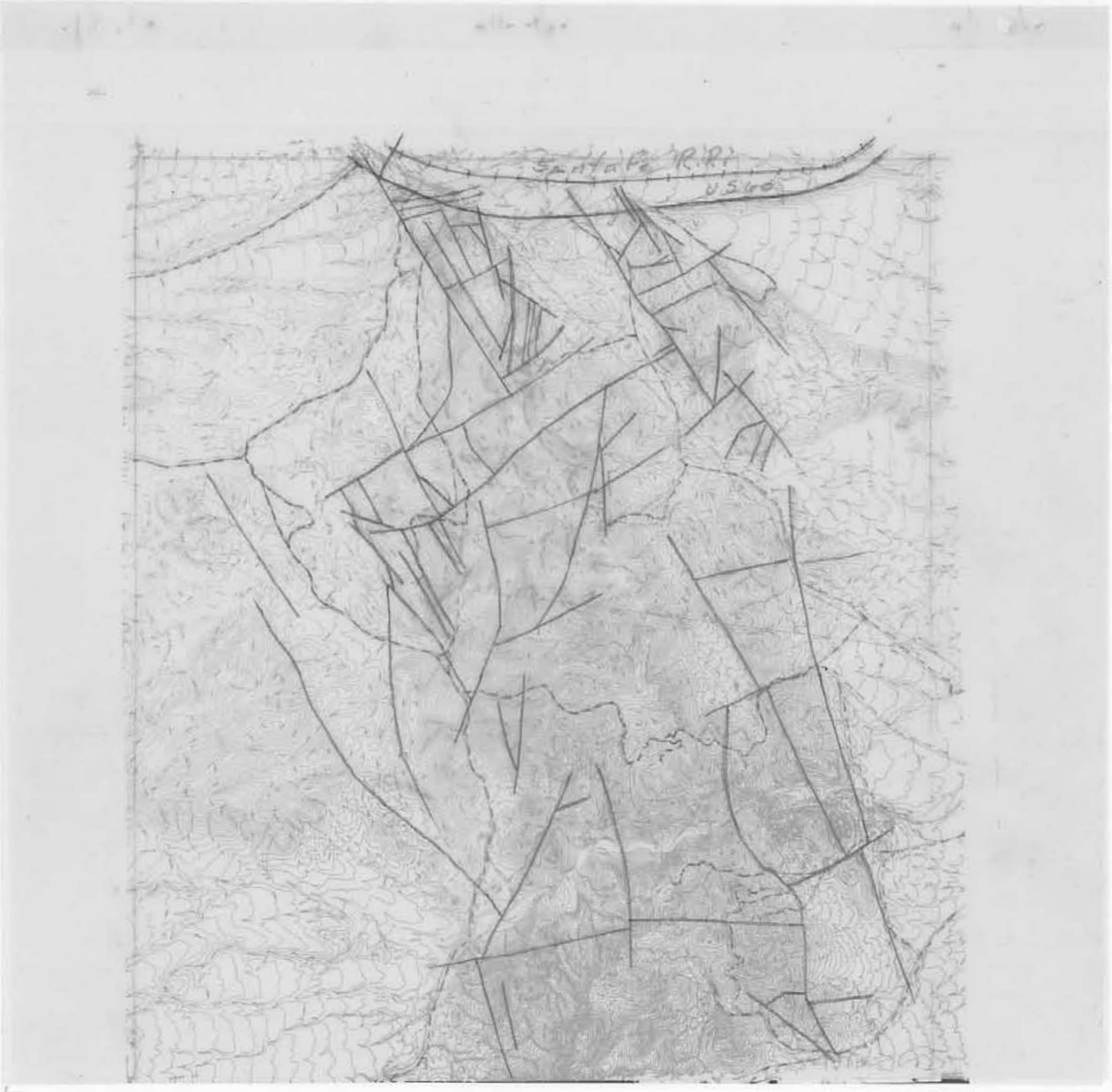


Fig. 11: Fault patterns in the northern Chupadera Mountains.
Scale: 1" = 1 mi.

following p 46 OFR 156 #5

## Summary

The field evidence does not indicate a general time succession for the formation of the faults. The north-northwest faults at places offset and at other places are offset by the east-west faults, and these fault groups may offset or be offset by cross-faults. It appears that, in general, the faults within and bounding the mountains developed penecontemporaneously and probably are products of a single tectonic event.

No ¶ The northern Chupadera mountain block is bounded by faults and stands in ~~relief with~~ respect to its surroundings. ~~It is~~ a structurally elevated block that could have originated as a result of normal down faulting east and west of its boundary zones or by actual uplift of the mountain block. No evidence of the absolute direction of motion could be obtained from the faults themselves, but physiographic evidence clearly indicates that the mountain block was actually uplifted.

The pediment surface on the Popotosa (?) formation is involved in the faulting, but the segments of the pediment east and west of the mountains are not displaced (Fig. 8). They are undisturbed parts of a slightly concave east sloping surface that once was continuous across the entire area (See profile plate I). The streams on the pediment east and west of the mountains are flowing close to grade and have developed meandering courses. Where these meandering streams cross the mountains they are deeply incised and are antecedent to the mountains. The Chupaderas have been pushed up through the pediment surface by an amount equal to or greater than their present relief ~~(Fig. ___)~~.

# MANGANESE MINERALIZATION

## Distribution and Occurrence

Manganese deposits are scattered in a north-south belt along the axis of the Chupadera mountains. Production has come largely from two areas; one in the northwest part of the district, and the other in the southeast, south of Red Canyon. Between these areas are numerous small prospect pits, development cuts, and shallow shafts
Plate - 1
(~~Fig. ______~~).

Manganese oxides are disseminated throughout the mineral belt. All deposits contain various combinations of these oxides. In the developed mines these oxides are concentrated along narrow parallel fault openings or in wide irregular breccia zones. In both, the ore minerals were deposited in open spaces. The host rock at all the commercial deposits is ~~Tertiary~~ crystal tuff.

Surface exposures at most deposits are excellent and in addition vertical sections are still exposed in several of the larger open-cuts and in one underground mine. The Black Canyon mine, the deepest underground mine in the district is no longer accessible.

## Mineralogy

### General Statement

All the ore ~~minerals~~ occurs as banded reniform ~~uniform~~ fibrous masses in the larger open spaces along faults (Fig 12) and as thin fibrous films and veinlets in the tighter breccia zones (Figs. 13 ).

Fig. 12: Specimen of reniform ore minerals from the vein at the Tower mine.

Fig. 13: Polished specimen of the breccia ore from the MCA mine. Bright metallic layers around breccia fragment are manganese oxide; larger open spaces are filled with calcite.

following p49

Psil~~a~~omelane, hollandite, coronadite, and cry~~s~~pt~~a~~omelane have been reported in the ~~areas~~ ores of the Luis Lopez district. Calcite and "black calcite" are the principal gangue minerals. Both minerals occur as veinlet cutting the ore and as finely crystalline coatings on the reniform surfaces of the ore. Large veins of white and black calcite, several feet wide, also occur as separate veins in the country-rock. Very minor amounts of fluorite are present in some deposits. Small amounts of barite occur in veins and drusy cavities in the country rock. Anhydrite and associated gypsum have been reported to be present in the ore (Jicha 1956). Thick fibrous reniform crusts of goethite occur with the manganese minerals at one deposit. Chalcedony is ubiquitous but a minor constituent of the ore. It is bluish-gray to white and occurs as veinlets and thin coatings.

Psilomelane

Psilomelane is orthorhombic but characteristically appears amorphous. The mineral is black with a submetallic luster. The ideal formula is $BaMnMn_8O_{16}(OH)_4$. Typical analyses show from 12 to 17 percent BaO. It commonly contains Cu, Co, Ni, Mg, Ca, W, and the alaklies. These elements may be adsorbed, admixed or possibly substitute for Ba and Mn. Many elements in addition to those listed above were identified in the Luis Lopez ore.

Based on x-ray powder diagrams Miesch (1956 p 25) concluded that the most prominent ore mineral in the Luis Lopez district was psilomelane. Although not predominate, psilomelane was also reported by Hewett (1964, p. 1440) in ore from several of the Luis Lopez deposits.

## Hollandite

Hollandite is tetragonal or pseudotetrogonal and occurs in short prisms or massive fibrous aggregates. It is an oxide of barium and manganese, probably $MnBaMn_6O_{14}$. Analyses indicate the mineral contains from 17 to 20 percent BaO and an excess of trivalent metals including iron. Hollandite is silvery gray to black with a bright metallic luster.

Hollandite was identified by Hewett (1964) and Jicha (1956) in ore from the Luis Lopez district. These identifications were based on x-ray studies.

## Corona~~l~~dite

This mineral is an oxide of lead and manganese, its probable formula is $MnPbMn_6O_{14}$. It is pseudotetragonal and characteristically occurs in fibrous reniform crusts. It is isostructural with hollandite. Coronadite is dark gray to black and has a dull to submetallic luster.

Coronadite was identified by Hewett (1971) in samples from the Luis Lopez district. It is the principal manganese mineral at the Optimo mine and minor amounts have been identified in ores from other deposits. On the basis of spectrographic analyses the Optimo ore contains from 15 to 20 percent lead. Type material from the Coronado vein, Clifton-Morenci, Arizona contains approximately 28 percent lead oxide.

## Cryptomelane

Cryptomelane is a potassium bearing member of the psilomelane minerals (Richmond and Fleischer, 1942). Potassium is not present in fixed amounts hence the formula $KRMn_7O_{16}$ has been suggested for crystomelane. Potassium in recorded analyses of specimens identified as cryptomelane ranges from a few tenths to 6 percent. Like psilomelane it may contain a number of additional elements. Crystomelane is dull brown and characteristically fibrous.

Hewett (1964) reported cryptomelane in several ore samples from the Luis Lopez district. It was tentatively identified (Jicha 1956) in the fibrous surface layers that occur in some ore samples. These identifications were based on x-ray diffraction data.

"Black calcite" from a vein near the southwest end of Red Canyon was leached with dilute hydrochloric acid. X-ray and atomic absorption analyses indicate the resulting insoluble residue is cryptomelane. The atomic absorption analysis shows the presence of 1.05 percent potassium, 0.16 percent lead, and barium was not detected. Table 1 presents the results of the x-ray analysis. The "d" values for hollandite are also included in the table, and are essentially the same as those obtained from cryptomelane. On the basis of x-ray data cryptomelane and hollandite can be distinguished from psilomelane and coronadite but cannot be distinguished from each other. Similarly, it is difficult to distinguish psilomelane from coronadite. Manganese oxides tend to retain by sorption many of the heavy metals and other elements present in the ore depositing solutions and in later circulating groundwater, hence even with chemical data positive identification is difficult. This is especially true in the fine grained ore of the Luis Lopez type.

## Goethite

Goethite is an orthorhombic hydrogen iron oxide ($HFeO_2$). It is typically a secondary mineral derived by weathering from other iron bearing minerals. It rarely forms as a low-temperature hydrothermal vein product, but this is the origin in the Luis Lopez deposits.

Goethite although not previously reported in Luis Lopez ore is present in most deposits and is a major constituent at the Bursum mine. It occurs as fibrous reniform crusts that range up to several inches thick. These crusts of goethite coat the walls of cavities in the ore and adjacent country rock. Many of the goethite layers are coated with calcite and at places brecciated goethite is cemented by calcite. Small goethite stalactites are common. Chemical analysis of a sample of goethite from the Bursum mine showed the presence of the following minor elements: Ba--0.21%, Pb--0.216%, Zn--0.365%, W--0.018%, Mo--0.011%, Cu--0.075%, Co--0.002%. These elements are also present in the manganese oxides and except for barium and lea in approximately the same amounts.

## Gangue Minerals

Calcite, chalcedony, quartz, barite, fluorite and anhydrite all occur at various places, but only calcite, chalcedony, and quartz occur in appreciable amounts.

Fluorite has been observed in small amounts scattered through ore from the Tower and Optimo mines. Jicha (1956) reported that barite in minor amounts is always associated with the manganese minerals. This observation was not verified by the author. All the barite seen occurred in veins and scattered clusters of tabular crystals in cavities in the country rock. A quartz vein three quarters of a mile north of Box Canyon and east of the Tower mine road includes along its edges layers of coarse plumose barite. The lower parts of these plumes contain disseminated iron oxide minerals in sufficient concentration to produce what might be called "black barite" (fig. 14).

Small colorless hexagonal crystals on tabular barite from a vug in the andesite at Box Canyon were identified as vanadinite by C. W. Walker. The identification is based on single crystal x-ray diffraction. This mineral has not been previously reported from the Luis Lopez district.

Small amounts of quartz and chalcedony are present throughout the district occurring both in the ore and country rock. Blue-gray chalcedony is present as thin crusts on and cutting the ore minerals. Most of the quartz associated with the mineralization occurs as thin layers of tiny clear crystals on the ore minerals and in small drusy cavities. Milky quartz veins and large areas of silicification occur as shown on Plate I. These occurrences are not associated with known ore bodies. Silicification north of the Bursum mine has converted parts of the volcanic breccia to a mottled red jasper. Relics of the breccia

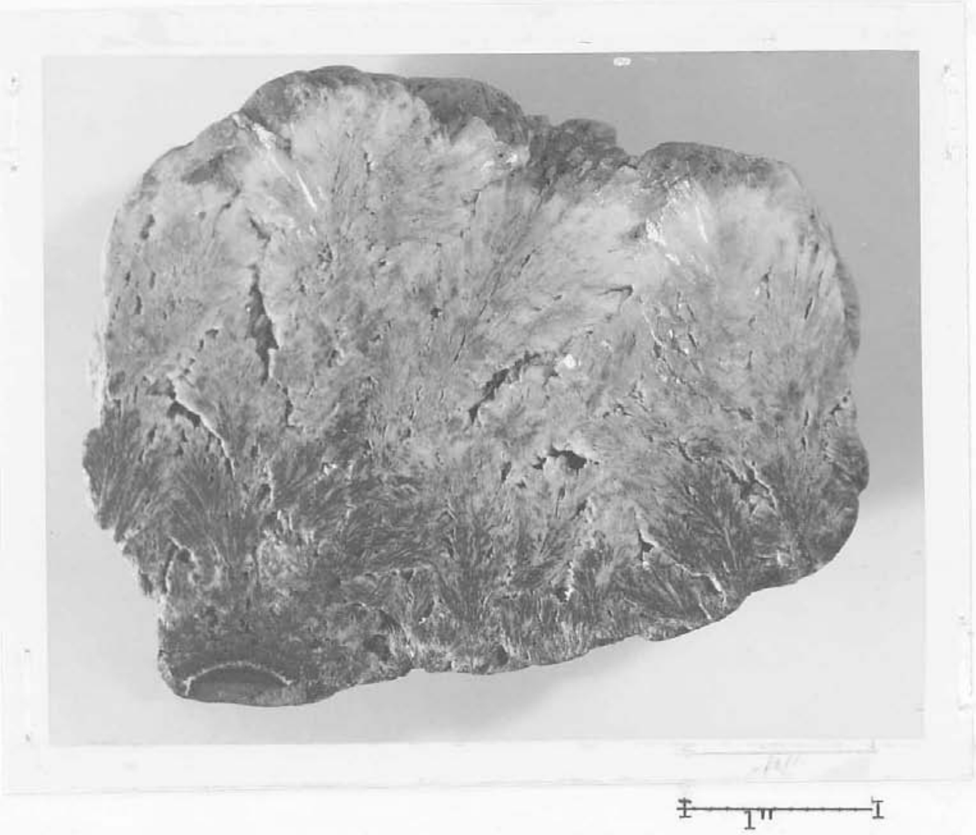


Fig. 14: Plumose barite from vein southeast of the Tower mine. The dark color at base of plumes is due to disseminated iron oxide.

following p 54

fragments are still present. This jasper was used by early Indians, and at several sites in the general area there are large concentrations of chips and damaged arrowheads. Anhydrite was not seen by the author but is reported (Jicha 1956) to occur as white to pale bluish-white crusts on the batryoidal surfaces of the ore minerals. The average thickness of these crusts is said to be ½-1 cm.

Calcite and "black calcite" occur in association with the ore and as separate veins in the country rock. Large veins of mixed black and white calcite, ranging up to several feet across are present in the MCA pit. Individual crystals an inch or more across are common (Fig. 15). The long axes of these crystals are normal to the walls of the veins and banding, due to a succession of depositional layers, is typical. These bands range from white to amber to black and are commonly cut by veinlets of either white or black calcite (fig. 16). At places thin bands of black or white calcite alternate with bands of manganese oxides. Tiny snow white crystals of calcite at places occur as frosting on the batryoidal surfaces of the ore minerals. This relationship is common and striking examples were observed in some of the large cavities encountered in the Nancy mine.

"Black calcite", as already noted, includes various amounts of finely crystalline manganese minerals. The black color of the calcite is due to these inclusions. In the sample examined the manganese oxide was largely cryptomelane, but caronadite and psilomelane have been recognized in "black calcite" from other districts. The manganese minerals in the Luis Lopez calcite may be either irregularly distributed

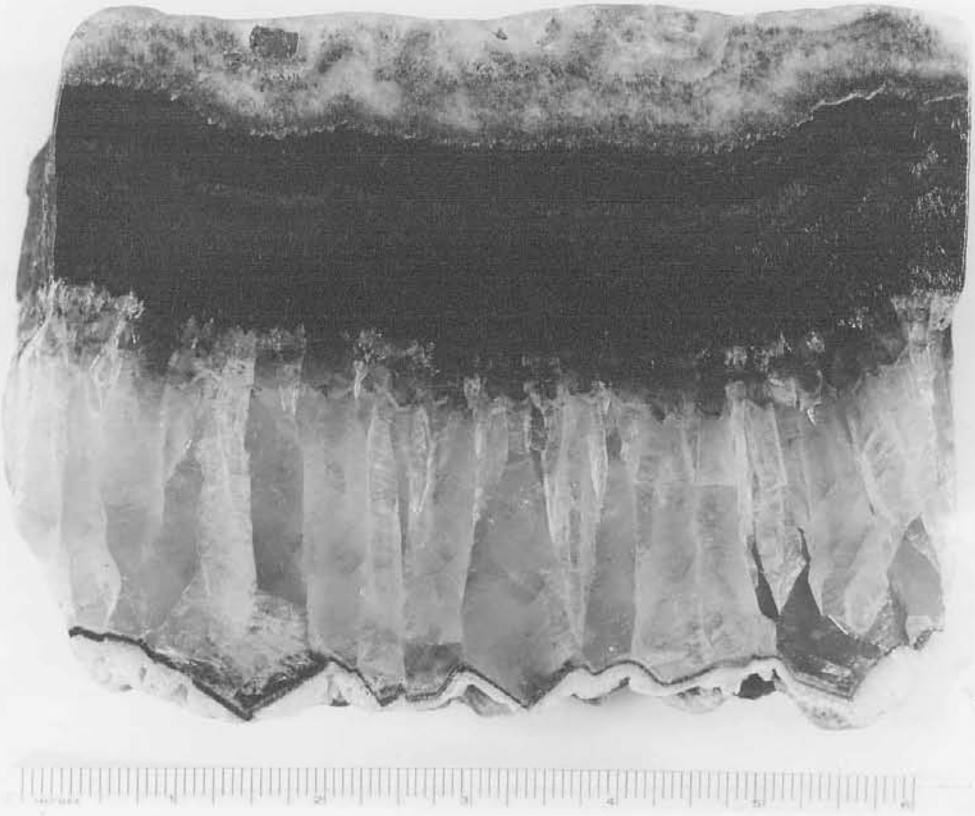


Fig 15: Coarsley crystalline black, white, and clear calcite from vein in the MCA pit.

Fig. 16: Banded amber to white calcite cut by veinlet of black calcite.

following p 55

in the calcite or regularly concentrated along crystal growth planes in the calcite (Fig. 17). Irregularly dispersed spherulites of manganese oxide are present in parts of the calcite (Fig. 18). These cocklebur-like masses and the calcite they are suspended in must have crystallized at essentially the same time.

## Paragenesis

All of the ore was deposited in open spaces. There is no evidence of wall rock replacement or replacement of earlier ore or gangue minerals. Hence the sequence of layers inward from the walls of the open spaces is also the order of their deposition, and obviously veinlets that cut across the layers are youngest. Applying these criteria the indicated sequence of mineral deposition differs markedly from place to place, even within a single hand specimen. It, therefore, appears that in general the minerals were all forming at about the same time. However, calcite may have continued to form for a time after deposition of the ore minerals. This is suggested by the presence of calcite veins that locally cut across some ore bodies and the occurrence of brecciated manganese minerals cemented by calcite (Fig. 29). Similarly, silica was deposited during and after the formation of the manganese minerals.

Barite was not observed in the ore, but the "black barite' observed in one quartz-barite vein indicates that a part of the barite and the iron minerals were deposited simultaneously. Vanadinite crystals were observed only on barite and obviously were deposited after the barite.

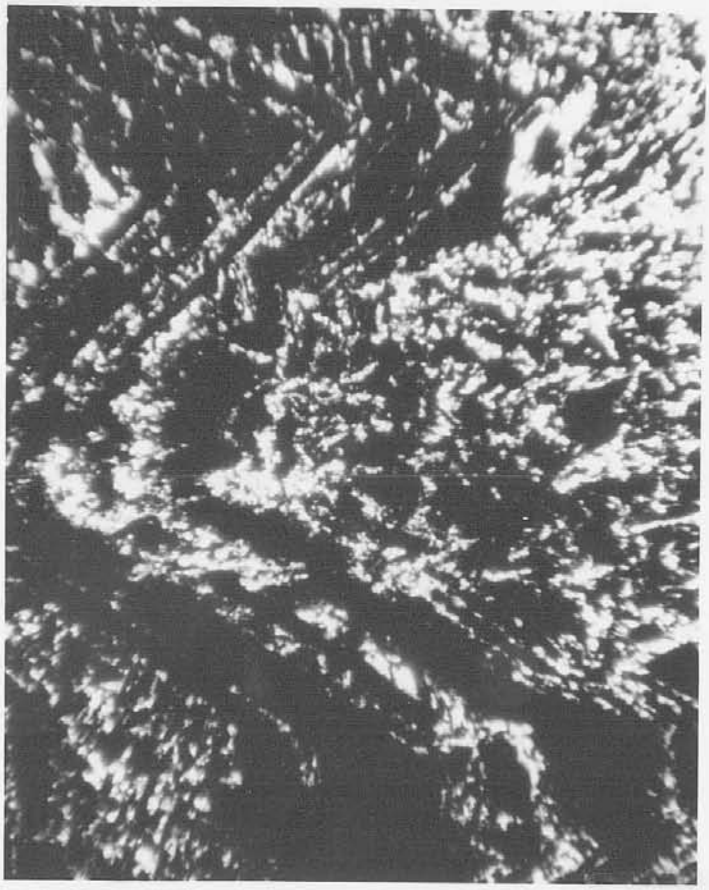


Fig 17: Microcrystalline cryptomelane co concentrated along growth planes in black calcite.

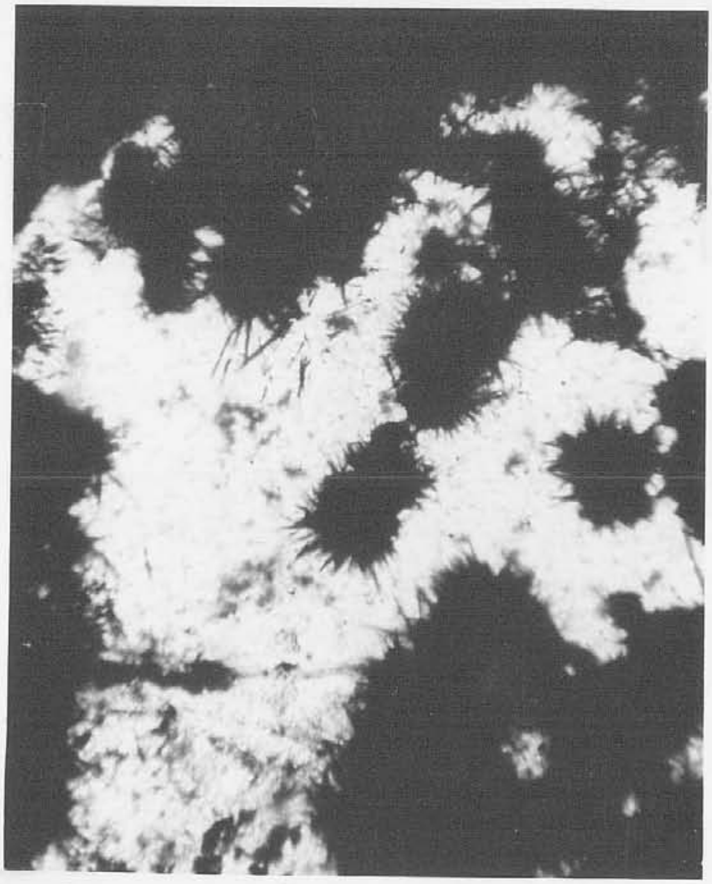


Fig. 18: Cocklebur-like aggregates of cryptomelane in black calcite

following p56

Fig. 19: Brecciated manganese mineral cemented by white, finely crystalline calcite.

## Ore Mineral Textures and Structures

All the b~~a~~otryoidal mineral crusts show some degree of layering. These layers range in thickness from a fraction of a millimeter to several centimeters and tend to be parallel to the free surfaces (Fig. 20). This layering of the manganese oxides is most highly developed in samples from the Tower-Black Canyon area.

On broken and polished surfaces alternate layers range from dull black to bright metallic gray. It has been suggested that the layers differ in mineral composition; alternating layers of psilomelane hallondite, and coronadite have been reported.

Electron microprobe analyses across a layered specimen of the Tower ore were made at the Metallurgical Laboratory of the White Sands Test Facility at Las Cruces, New Mexico. Tranerses were made for the essential elements, other than manganese, and for a number of the minor elements that are commonly present.

Only slight variation in the amounts of these elements were detected and none were systematically related to the very evident layering. Microprobe analyses were run on another sample by Dr. Kenneth Williams of Stanford University. He reported that the chemical variations across the layers were of the same order of magnitude as those observed along a single layer. Similar results were obtained by Corale Brierley in the laboratory of the New Mexico Bureau of Mines. It, therefore, must be concluded that the observed layering in these specimens, which appear to be typical, is largely due to physical differences unrelated to changes in mineralogy.

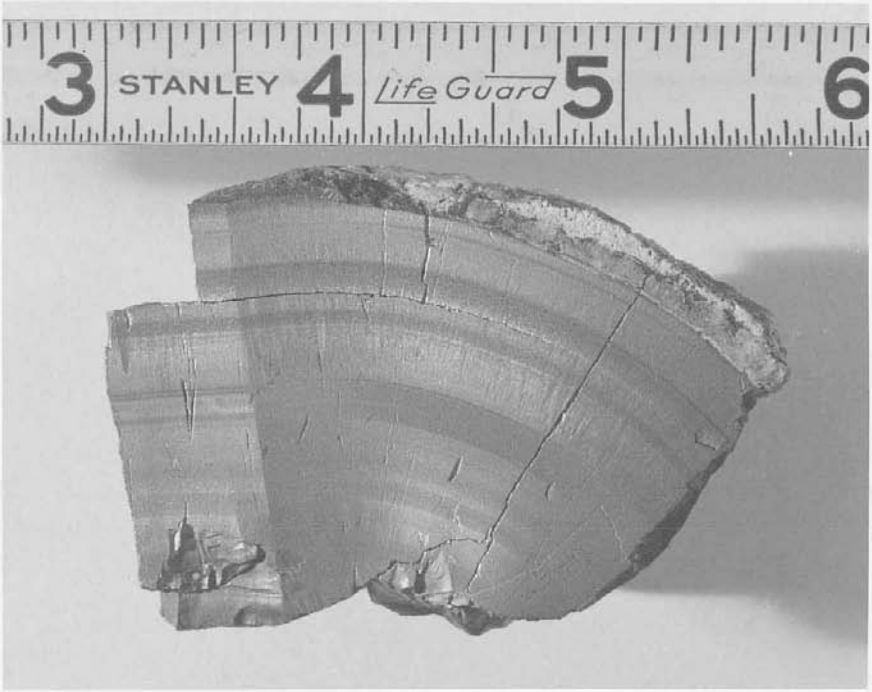


Fig. 20: Polished specimen of banded manganese ore from the Tower mine.

following p 57

It appears that the size of individual crystals and their aggregate orientation are most responsible for the observed banding. The minerals all tend to form acicular crystals that range from more than a centimeter long to submicroscopic. Characteristically these crystals grow in radially oriented groups. In general the ore is made up of layers of these erulite sphalerite-like crystal groups and amorphous appearing submicroscopic material. On broken and polished surfaces reflection banding is evidence of this layering. The reflectivity of the bands differ and reflections from the coarsely crystalline layers may change depending on the angle of observation. In some specimens bands and whole groups of bands will change from dull black to bright metallic and back as the specimen is rotated (fig. 20 ). Several of the crystal arrangement s/ that result in the is/ ~~variable~~ reflection banding ~~layering~~ are shown in figure 21 .

A reflection layer consists of radially arranged acicular crystals, and due to the radial arrangement of the crystals these layers have a chatoyant luster. Over all they may or may not appear metallic. Because of their radial arrangment the crystals during growth are not in contact at their outer ends. This results in what is locally and very appropriately called "rat hair" (figure 22 ). The free standing parts the crystals may be as much as a centimeter long and where undisturbed may be traced for some distance into the dense underlying ore. These free standing crystals are so delicate that even a gentle current of air will disturb them. Hence, the solutions in which they formed must have been essentially stagnant.

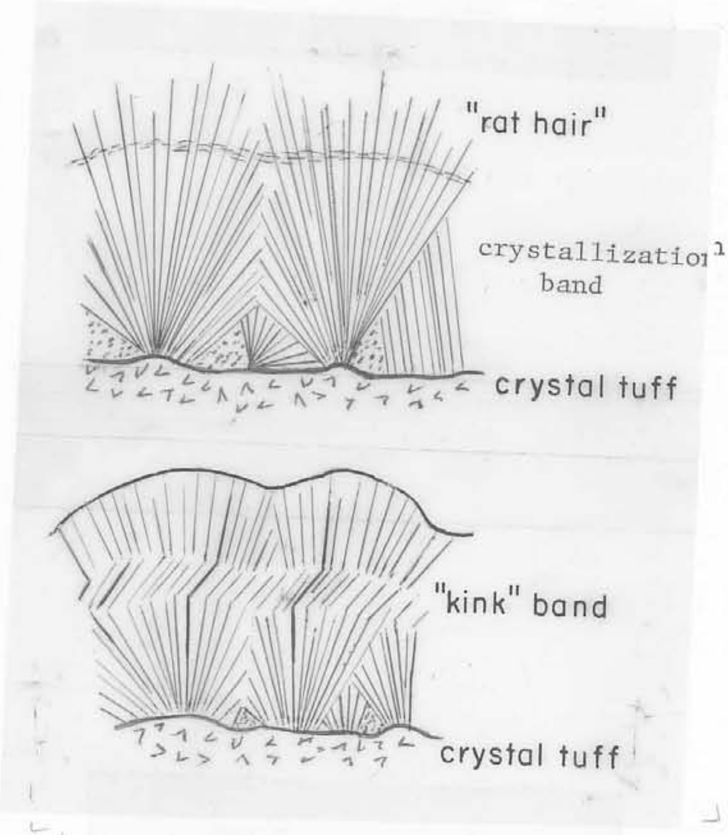
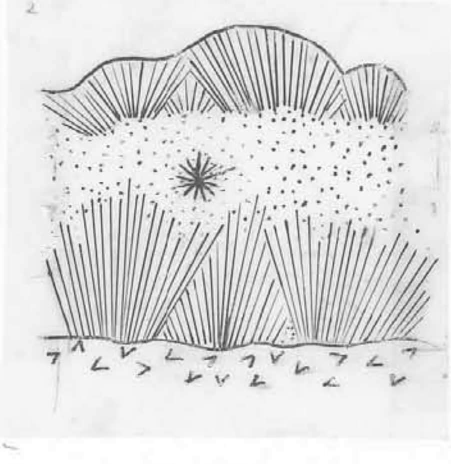


Fig. 21: Variations in crystal arrangement that produce reflective banding



following p 58

Fig. 22: Free standing fibrous manganese minerals, locally called "rat-hair" Sample is from Nancy mine. (2X)

following p 58

Table 1. X-ray Diffraction Data For Cryptomelane and Hollandite

| (1) | | (2) | | (3) | | (4) | |
|---|---|---|---|---|---|---|---|
| d(Å) | I | d(Å) | I | d(Å) | I | d(Å) | I |
| 9.55 | 20 | | | 9.37 | S | | |
| 6.91 | 100 | 6.9 | 100 | 7.02 | S | 7.02 | 1 |
| 4.95 | 25 | 4.9 | 70 | 4.96 | MS | 4.98 | 2 |
| 4.07 | 10 | | | 4.15 | W | | |
| 3.46 | 25 | 3.45 | 5 | | | 3.48 | |
| 3.13 | 30 | 3.13 | 90 | 3.12 | S | 3.13 | 10 |
| 2.39 | 40 | 2.40 | 100 | 2.40 | W | 2.39 | 6 |
| 2.15 | 10+ | 2.14 | 40 | 2.15 | W | 2.16 | 4 |
| 1.93 | 10 | 1.95 | 5 | | | | |
| 1.83 | 15 | 1.82 | 20 | 1.84 | VW | 1.84 | 2 |
| | | 1.63 | 10 | 1.66 | VW | 1.65 | 1 |
| 1.54 | 10+ | 1.54 | 30 | 1.55 | VW | 1.54 | 2 |

(1) Insoluble residue from black-calcite west end of Red Canyon. Analysis by C. W. Walker.

(2) Cryptomelane. Sorem and Cameron, Econ. Geol. v. 55, 278 (1960), A. S. T. M. A. 12-706.

(3) Cryptomelane. Frankell, Econ. Geol. v. 58, 591 (1958).

(4) Hollandite, Hewett, Econ. Geol., v. 66, 173 (1971).

following p 58

Table ~~IV~~.—Spectrographic analyses of ~~layers~~ Samples of ~~oxides~~ from the Tower and Optimo Mines, ~~Socorro County~~

| State | ~~New Mexico~~ | | | | |
|---|---|---|---|---|---|
| Sample | 1 | 2 | 3 | 4 | 5 |
| Lab No. | ~~634-24~~ | ~~634-25~~ | ~~634-16~~ | ~~634-17~~ | ~~634-18~~ |
| Mine | Tower 1 | Tower 2 | Optimo 1 | Optimo 2 | Optimo 3 |
| Collector | Hewett | Hewett | Willard | Willard | Willard |
| Host rock | Rhyolite | Rhyolite<br>crystal tuff | Rhyolite breccia | Rhyolite breccia<br>Tuffs | Rhyolite breccia |
| Si | 0.07 | 0.1 | 1.0 | 0.2 | 0.5 |
| Al | .5 | .5 | .7 | .7 | .7 |
| Fe | .03 | .03 | .1 | .07 | .07 |
| Mg | .02 | .005 | .015 | .015 | .02 |
| Ca | .2 | .07 | .1 | .07 | .05 |
| Na | .1 | .03 | .07 | .03 | .02 |
| K | .7 | 0 | 0 | 0 | 0 |
| Ti | .01 | .007 | .015 | .01 | .007 |
| P | 0 | 0 | .7 | .7 | .7 |
| Mn | M | M | M | M | M |
| Ag | .0002 | 0 | .00015 | 0 | 0 |
| As | .5 | .7 | .7 | .7 | .7 |
| B | 0 | 0 | .007 | .003 | .001 |
| Ba | 15 | 7 | 7 | 5 | 3 |
| Be | .0015 | .033 | .0015 | .0015 | .002 |
| Co | .03 | .01 | .02 | .01 | .007 |
| Cr | .003 | .007 | .015 | .015 | .005 |
| Cu | .07 | .02 | .05 | .02 | .01 |
| Ga | .007 | .005 | .01 | .005 | .003 |
| La | 0 | 0 | .01 | 0 | 0 |
| Mo | .07 | .03 | .15 | .1 | .01 |
| Nb | .003 | .003 | .005 | .005 | .005 |
| Ni | .003 | .003 | .003 | .003 | .0003 |
| Pb | 3 | 15 | 15 | 20 | 15 |
| Sb | .2 | .3 | .2 | .5 | .7 |
| Sc | .0015 | .002 | .0015 | .0015 | .0007 |
| Sr | .7 | .15 | .2 | .1 | .01 |
| Tl | .2 | .1 | .15 | .15 | .05 |
| V | .03 | .02 | .07 | .03 | .01 |
| W | .05 | .15 | .3 | .2 | .15 |
| Y | .002 | .002 | .002 | .002 | .0015 |
| Yb | .0003 | .0002 | .0003 | .0002 | .0001 |
| Zn | .7 | .7 | .5 | .3 | .15 |
| Zr | .0007 | .0005 | .0007 | .0005 | .0005 |

Sought but not found: Au, Bi, Cd, Ce, Ge, Hf, Hg, In, Li, Pd, Pt, Re, Sn, Ta, Te, Th, and U.

analyzed by D F Hewett,
U. S. Geol. Survey

Elements other than Mn & O

Manganese
and ~~[illegible]~~
oxygen

Atomic absorbtion

Pb - .001 - 20%
Ba - 5 - 19
Fe - 1 - 10
Cu - 0 - 0.13
Zn - 0.08 - $\overset{0.58}{0.6}$
Ni - 0 - $\overset{0.014}{\cancel{0.008}}$
Co - 0 - 0.70
W - 0 - 1.7
Mo - 0 - $\overset{0.181}{\cancel{0.08}}$
K - 0 - 2.0
Sr - 0 - 0.1

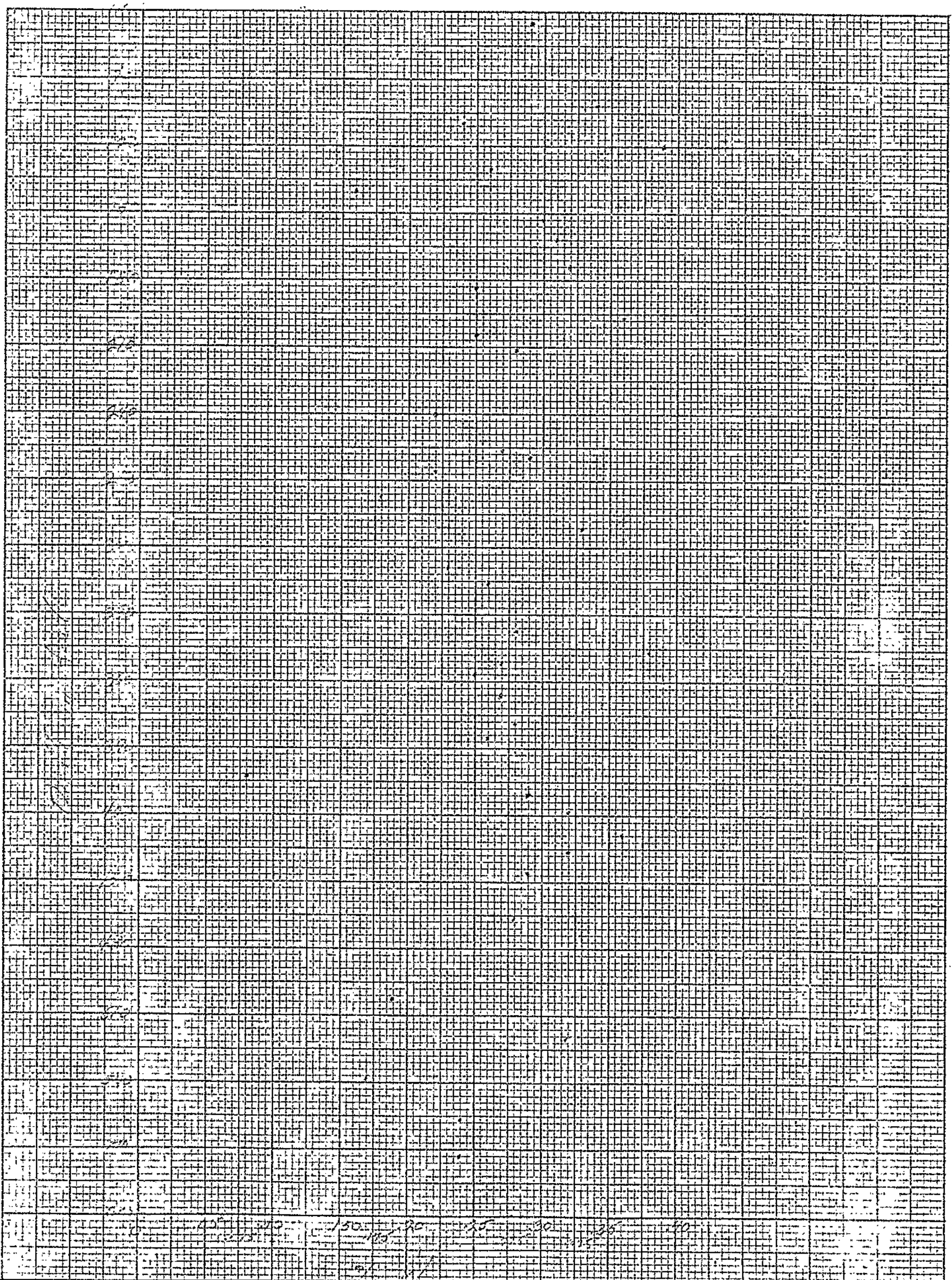
Spectrographic

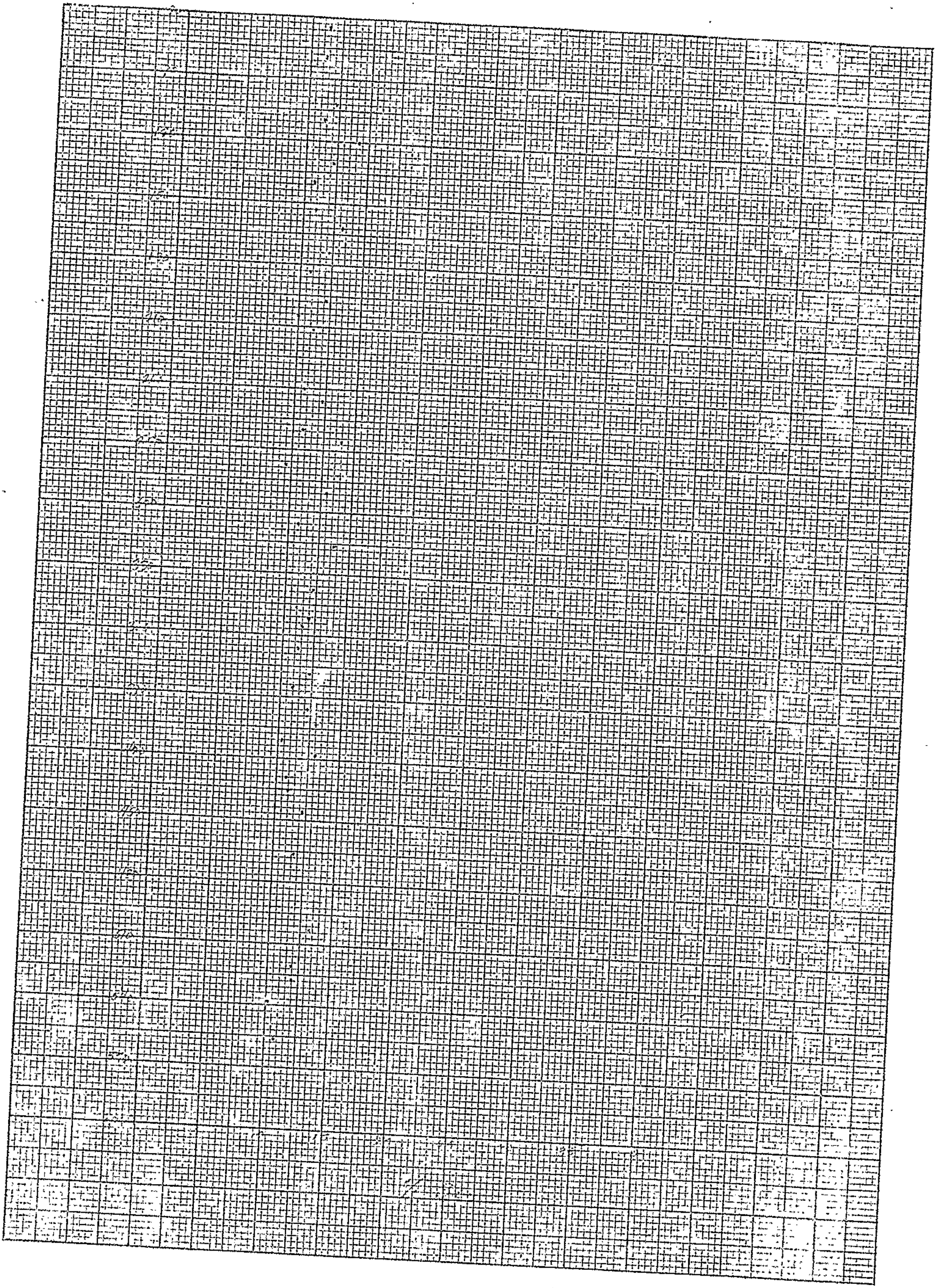
As - 0.7 - 1.5%
Sb - 0 - 0.7
Tl - 0 - 0.7
Be - 0.003 - 0.007
Mg - 0.03 - 0.15
Ca - 0.3 - 1.5

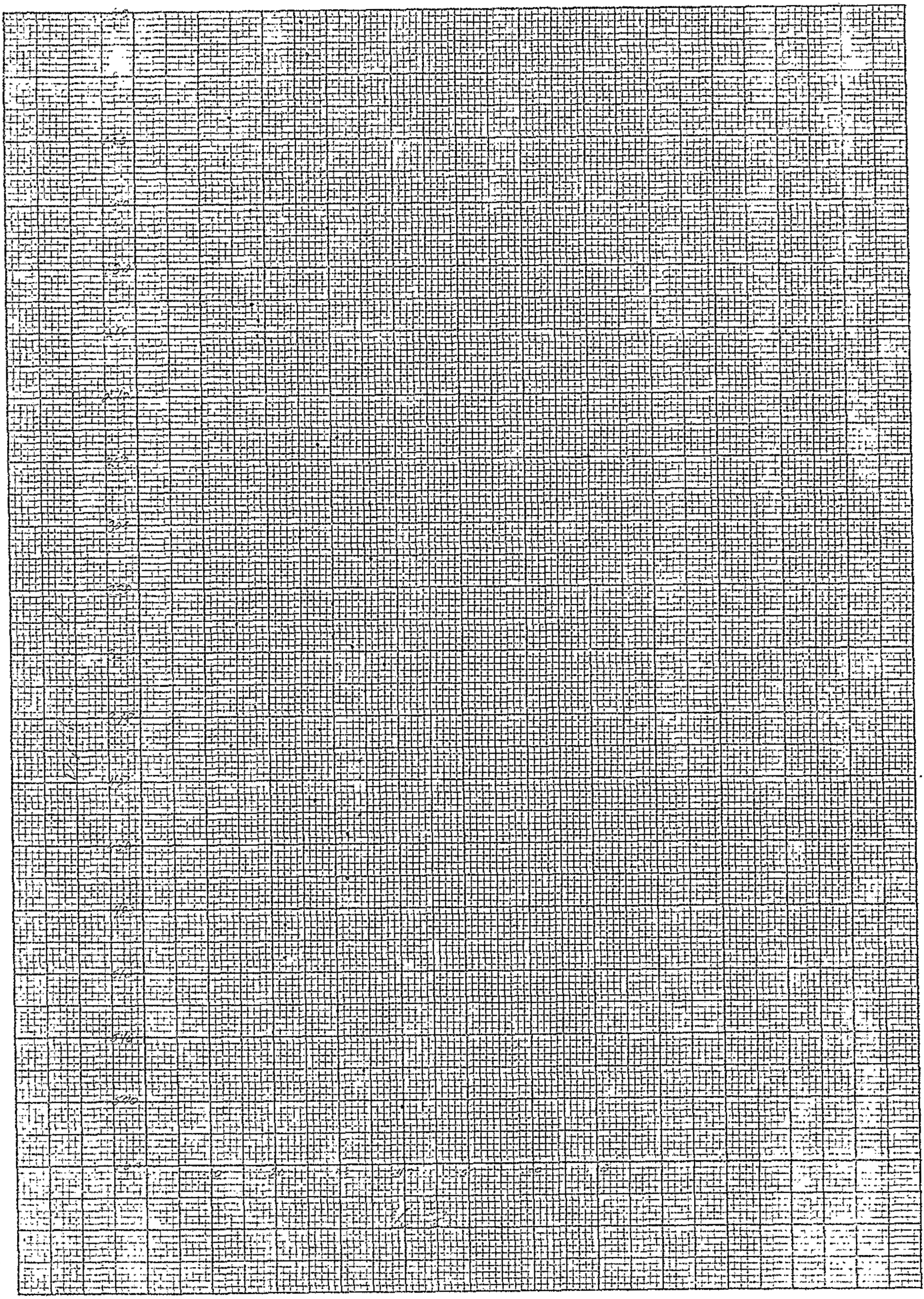
Fire assay

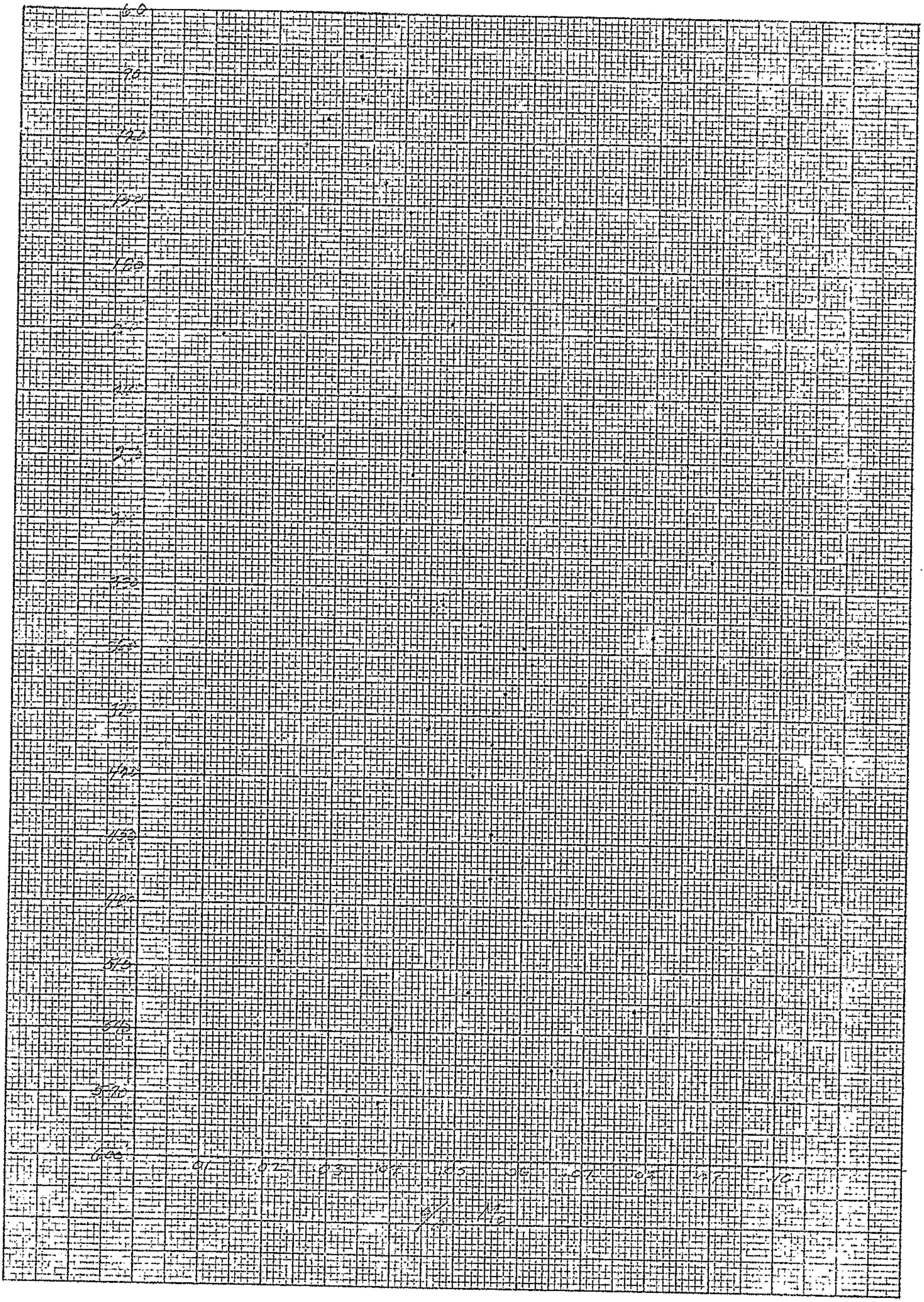
Au - 0 - 0.02 oz/Ton
Ag - 0 - 3.30 " / "

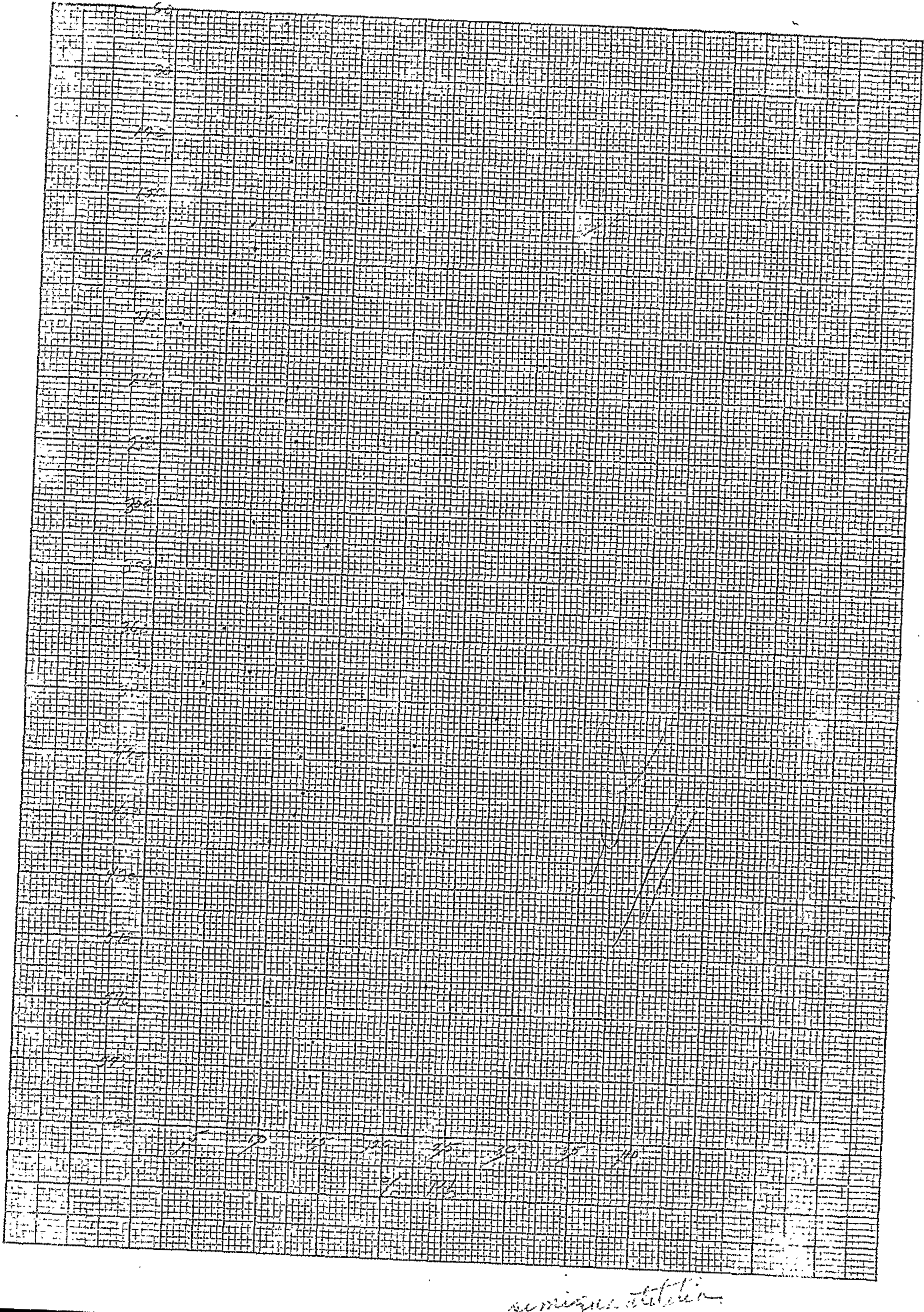
Ranges in % | most common occurring elements in the ore minerals?


150
30
35
40






60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
B/N₀


50
150
300
5
10
15
20
25
30
35
40

[illegible]

In summary, the observed differences from layer to layer in the ore are attributable to differences in orientation and degree of crystallization. The electron microprobe analyses showed little change in the composition of the layers. Hence it may be concluded that the layering in the ore is due more to small variations in the physical environment of deposition than to changes in the composition of the depositing solutions.

As already stated, manganese minerals in addition to occurring in faults and brecciated zones, are also disseminated throughout the crystal tuff. These disseminated minerals occur mainly in closed cavities along partially healed small randomly oriented fractures. These fractures probably developed from compaction and contraction during the early history of the crystal tuff and therefore may be considered as initial cavities. The manganese minerals for the most part occur in scattered half beads 1 to 2 millimeters across on the walls of these cavities (Fig. ______). Structurally the beads are made up of a series of concentric fibrous and granular layers. They have features that are similar to the exfoliation spheroids described by Lebedev (1967, p. 42). Many are attached only at their core and with slight pressure the outer layers will separate. The newly exposed surfaces may be covered with a short stubble of "rat hair" or amorphous appearing material, probably an iron oxide. Each of the spheroids has roots that extend for a short distance into the intergranular spaces of the crystal tuff. Mineralogically they are the same as the ore.

The cavities in which these spheroids occur are not part of a through going circulation system. Hence, the depositing solutions must have entered through the walls of the cavities and it seems probable that the solutions were generated in the surrounding crystal tuff.

## Chemical Composition of the Ore Minerals

Thirty one elements other than manganese and oxygen have been identified in the ore minerals of the Luis Lopez district (Table________). Several of the elements are present in potentially valuable amounts. The range in percent of a number of these accessory elements is shown in table__________.

Preliminary chemical analyses of the Luis Lopez ore minerals by Jicha (1965) suggested a systematic increase in the amount of lead from south to north in the district. He suggested that, "the highest lead values occur in the northwest part of the district, at Black Canyon where the intrusion of the "massive rhyolite" (crystal tuff) took place. His suggestion of a horizontal zoning pattern for lead prompted the present more thorough investigation of the horizontal and vertical distribution of lead and other accessory elements.

Where possible the principal mines were sampled in detail and chip samples were taken from a majority of the prospect pits and natural exposures. These samples were analyzed by atomic absorption. The vertical distribution of the minor elements was determined by analyses of samples from the Tower mine diamond drill hole and from the Black Canyon mine shaft. The core samples were from the bead-like concentration in initial cavities, and represent the complete thickness of the crystal tuff. These core samples were analyzed by semiquantitative spectrographic methods. The Black Canyon shaft samples were analyzed colorimetrically and by atomic absorption; and were also fire assayed for gold and silver by Dr. G. V. Greene. The results of this analytical work are shown on Plates ______ and ________, and Fig. ____.

The average content of lead tends to be highest in the northern deposits. However, the range in percent lead at the Tower pit near the north end of the district, is as great as the range previously recognized for the whole district. Semiquantitative analyses have shown a similar range in a single small sample. The highest lead values obtained were from the Optimo tunnel, they ranged from 12.30 to 20 percent. There are few known manganese deposits north of the Optimo but samples from one approximately 3/4 of a mile north-northeast of the Optimo contained only 1.07 percent lead, which is inconsistent with the earlier suggested zoning. Analyses of the samples from the Black Canyon shaft indicate that there is no systematic change in the amount of lead with depth. Lead in the shaft samples range from 0.42 to 2.54 percent. The drill core samples were analyzed by semiquantitative spectrographic methods and spot analyses by x-ray fluorescence were made to check their accuracy. The spectrographic analyses were consistantly too high. The x-ray analyses suggest the range is between one half and two percent.

Barium is present in all samples but is not systematically distributed either horizontally or vertically. The average amount is between 10 and 12 percent and the range is from 5 to 19 percent. In general it appears that if the amount of barium in a sample is low the amount of lead is also low; they do not vary inversely as might be expected.

A sufficient number of analyses for tungsten, molybdenum, copper, and zinc have been made to establish that they also are haphazardly distributed both horizontally and vertically.

Most samples contain between .1 and .3 of a percent tungsten, the observed range is 0 to 1.7 percent. The sample containing 1.7% was from the Niggerhead pit in Six Mile Canyon west of the mapped area. Another sample from the same pit contained no tungsten.

Molybdenum normally is present in the ore minerals but seldom in amounts in excess of a few hundreths of a percent. However, 0.112 and 0.818 of a percent were present in samples from the 250 and 350 foot levels of the Black Canyon mine. On the 400 foot level the percent molybdenum dropped to 0.053. One shipment of ore from the 350 foot level was rejected because it contained an excessive amount of molybdenum (L. A. Garet, oral communication).

Zinc and copper, in small amounts, are present in all samples. Zinc ranges from 0.08 to 0.58 and averages between 0.2 and 0.4 percent, the average in the State Lease pit is slightly higher. Most samples contain only a few hundreths of a percent copper, the range is from 0 to 0.13.

The distribution of accessory elements, other than those discussed above, was not determined. However, analyses of a number of spot samples have shown that arsenic, antimony, beryllium, nickel, cobalt, strontium, thallium, gold, and silver are generally present. Unusual amounts of arsenic, antimony, cobalt and thallium are present in some samples. Analyses show as much as 1.5 percent arsenic and 0.7 percent each of antimony, cobalt and thallium. Traces of gold and silver were spectrographically identified in many samples. One sample from the Optimo mine and one from each of the four level of the Black Canyon mine were fire assayed. The results of these assays are listed below.

| | | |
|---|---|---|
| Optimo Mine | 1.06 oz/ton, Ag | 0.02 oz/ton, Au |
| Black Canyon | | |
| Level-1 | 0.68 | 0.01 |
| Level-2 | 0.68 | 0.01 |
| Level-3 | 0.20 | 0.01 |
| Level-4 | 3.30 | 0.00 |

Lead, barium, and potassium are essential parts of the minerals psilamelane, hollandite, coronadite, and cryptomelane. Psilomelane should contain between 12 and 17 percent barium, hollandite between 17 and 20 percent barium, coronadite approximately 28 percent lead. The amount of potassium in cryptomelane is not fixed. If these are valid mineral species then the observed wide variation in the amounts of lead, barium, and potassium in the ore must indicate that in general the ore consists of a very intimate mixture of these minerals.

It is well known that manganese oxides act as a "sink" for other elements, especially the heavy metals, but the mechanism by which these elements are fixed in the manganese oxides is not well understood. Suggested mechanisms include: (1) incorporation in the crystal latice, (2) occlusion of foreign ions or microcrystals, and (3) surface or interlayer sorption. All of these mechanisms, except possibly occlusion of microcrystals, may have been involved in the fixation of the accessory elements in the Luis Lopez ore. Foreign microcrystalline phases were not observed optically or by scanning electron microscope.

The immediate source of the accessory elements is also uncertain. They could have been derived from either meteoric or telluric solutions. If the deposits are hypogene, as has been suggested (Jicha 1956, Hewett 1964), it ~~is~~ follows that most of the accessory elements are also hypogene. Analyses of hot spring deposits from volcanic regions show most of the elements identified in the Luis Lopez ore. The gangue minerals in the Luis Lopez deposits are also commonly associated with hot spring deposits. These springs are generally assumed to consist of mixed meteoric and magmatic solutions. Many of the trace elements in these solutions, especially fluorine and arsenic, have been considered evidence of magmatic contribution. Hence, the presence of these elements in the Luis Lopez deposits suggests the ore solutions were at least in part magmatic. Whether the magmatic contribution was derived directly from ascending magmatic water, as implied by the term hypogene, or indirectly releases from the surrounding volcanic rock cannot be determined from chemical data.

## Ore Genesis

### Source of Ore Forming Solutions

The pressure of excessive amounts of potassium in the host rock and the alteration of plagioclase and other minerals to K-feldspar, albite, sericite, and kaolinite, as already described, occurs throughout the crystal tuff. This alteration doesn't increase in intensity or change character in areas adjacent to ore bodies, but tends to be most intense in the upper two thirds of the tuff. Much of the alteration probably was produced by a potassium rich solution that completely permiated the tuff. Sheridan (1970) reported that the fumarolic mounds in the Bishop tuff, California were so strongly enriched in potassium and aluminum that it was difficult to assign theoretical mineral phases. This probably would also be true for the Luis Lopez crystal tuff. Widely disseminated manganese mineral s, ory ore associated with the Luis Lopez alteration and it seems that the solution that altered the tuff also deposited these minerals.

The distribution and nature of the alteration in the crystal tuff precludes the possibility that it is a product of weathering, and since the ore mineralization and the alteration are genetically related the ore cannot be of supergene origin. Jicha (1956) and Hewett (1964) concluded that the Luis Lopez manganese deposits were hypogene and were deposited by ascending hydrothermal solutions. Their conclusions were based on general geologic relations and the distribution of accessory elements in the ore. Hewett further postulated a genetic similarity between these manganese deposits and epithermal gold-silver and base-metal deposits. He suggested that the Luis Lopez deposits might be succeeded in depth by barite, fluorite, gold-silver mineralizations. The information obtained from the Tower diamond drill hole doesn't support this suggestion (Fig. ________). Jicha's suggested zoning of base-metal content in the ore of the Luis Lopez district was not verified by the present study (Fig. ________).

It is clear that the mineralizing solutions were hydrothermal, but it is not clear that they were of much later origin than the enclosing rock or derived from some underlying source. The Luis Lopez manganese deposits do not fit precisely in to any genetic classification of mineral deposition.

The alteration and the ore mineralization are largely confined to the crystal tuff, but at a few places extends a short distance into the immediately overlying rock. None of the rocks exposed below the crystal tuff have been mineralized even though some are compositionally similar to the tuff. It, therefore, seems unlikely that the ore was deposited from ascending solutions. Fluorine, and trace amounts of arsenic and antimony have been accepted as evidence of the presence of juvenile water in hot springs and their presence in the manganese ore supports a similar conclusion concerning the mineralizing solutions. Evidently the ore-bearing solutions contained juvenile water but were not epigenetic or derived from some underlying magma. These relations, which appear contradictory, are accounted for if the ore solutions were released from the crystal tuff. Under these conditions the source of the solution is a pyroclastic. Therefore, the alteration and mineralization cannot be deuteric in the usual sense. Most of the juvenile gases associated with the eruption of the crystal tuff would be lost during or shortly after emplacement of the tuff. In as much as the ore was deposited after emplacement, comp~~osi~~action and welding of the crystal tuff, these initially released gases could not have been the source of the ore.

R. L. Smith (1960) has suggested that a period of dormancy exists between the time of compaction and welding of a tuff and the release by crystallization of the gases in solution in the glass fraction of the tuff. M.F. Sheridan (1970) in his theory of fumarolic development suggested that the water and other volatiles were released after welding and during divitrification. From the available geologic data it seems likely that the solutions that altered the crystal tuff and deposited the Luis Lopez ore had a similar origin.

The mineralizing fluids released by crystallization moved through the body of the crystal tuff and collected in earlier developed open ~~fractures~~ spaces. The survival of the very delicate "rat hair", at many places in the ore, indicates that the deposition solutions were essentially stagnant, at least during the late stages of deposition. The slightly mineralized basaltic andesite and tuff breccia that overlie the crystal tuff in the

Tower-Black Canyon mine area must have been emplaced before all the manganese minerals were deposited and therefore may have impeded the normal upward circulation of the ore bearing solutions. Probably the ore bodies developed within the crystal tuff because of this obstruction to the flow of solutions.

## Structural Control

The ore of the Luis Lopez district was deposited in openings produced by fracturing. These fractures can be separated into groups that differ in character, origin, and time of formation. The earliest probably developed during compaction of the tuff. They appear to be randomly oriented and to have been partly resealed by welding. This partial sealing has produced scattered small lenticular closed cavities that now contain bead-like aggregates of manganese oxide.

Joints which developed after the compaction and welding, and probably are related to the release of thermal stresses, occur throughout the tuff. Locally this jointing is intense and its pattern complex (Fig. ____). The joints may strike in any direction and range from vertical to nearly horizontal. Commonly the joints are curved and many are convex to the upper surface of the tuff. Downward they appear to merge into narrow nearly vertical breccia zones.

This joint pattern which is best exposed in the west pit at the MCA mine, suggests that the heat flow in the tuff was downward and toward the breccia zones. This rather anomalous heat flow pattern might be accounted for if the crystal tuff was covered by hot eruptive rocks during late stage in the cooling history of the crystal tuff. The rocks that overlayed the tuff at the MCA mine have been removed, but in the Tower-Black Canyon area, as noted, andesite and tuff breccia overlie the crystal tuff and were emplaced prior to the last stages of mineralization. These rocks or their equivalents probably covered the "—Hole district".

Jointing of the above type has controlled the deposition of most of the ore minerals from the MCA pits. The largest and richest of the ore pods were encountered along the vertical breccia zones. However, these accounted for only a small part of the production. Most of the ore recovered was from thin veneers on the surfaces of joint blocks.

The two most productive deposits, the Black Canyon and the Tower, are in north-northwest fault zones. Displacement in these zones is generally less than a hundred feet. Massive ore shoots were encountered in the larger open spaces and mineralization extended a short distance into the adjacent brecciated rock. The faulting that controlled the deposition of these deposits probably was initiated early and as already noted is continuing at present. Brecciated ore minerals are present in the gauge along some of the faults at Black Canyon and in the MCA pit. Singificant movement must have occurred after and possibly during deposition of a part of the ore.

# MINERAL DEPOSITS

## Introduction

The location of 73 known manganese deposits are shown on the geologic map (Plate________). The names and location of the principal mines and development pits are shown on figure_________.

The major part of the production from the Luis Lopez district has come from four mines; the Black Canyon, Tower, Nancy, and MCA. These mines and others were examined by L. L. Farnham (1961) in 1958; at that time several of the mines were still in production. His excellent report includes descriptions of the mining and milling methods; and the history of development, ownership, and production. These data will not be repeated here. The following parts of the report will deal mainly with the geology at the deposits.

## Black Canyon Deposits

### Introduction

Black Canyon is in the northern part of the district (Plate_______). The deposits in this area all occur along a north-northwest trending ridge on the west side of the canyon near its head (fig.________). Most of the mine roads are still in good condition and all deposits are easily accessible.

There are seven manganese mines in this area and each has been developed to some extent. Only the Black Canyon, Tower, and Nancy mines have been significantly productive. All the mines are at present inactive, the last in operation was the Nancy which shut down

October 20, 19~~2~~70. The Black Canyon mine was closed a year earlier. The air shafts at the Nancy have been bulldozed shut, but the portal to the first level was still open in 1972. The shaft and all tunnels at the Black Canyon have been closed, hence the workings are inaccessible. The portal to the Optimo (Blue Gold) mine is still open but it is reported that caving has closed much of the mine. All the other deposits were worked from open pits and are still accessible.

The Black Canyon and the Nancy were the only successful underground mines in the district. They also were the only mines that were profitably worked after the Deming, New Mexico, General Services Administration manganese-purchasing depot closed in 1955.

## General Geology

The general geology in the Black Canyon area is shown on plates ________ and ________. Crystal tuff (Tx), basaltic andesite (Tba), tuff breccia (Ttb), and welded crystal rich tuff are exposed at the surface. In additon to these units: rhyolite tuff (Trt), volcanic sandstone (Tvs), flow banded rhyolite (Ttr), and altered latitic tuff were encountered in the diamond drill hole at the Tower mine (Plate----).

In the Black Canyon area, as elsewhere, the Chupadera horst is highly faulted. The majority of the faults trend roughly north-northwest and dip a few degrees either side of vertical. Displacements are generally less than 100 feet. In the northern part of the area these north-northwest trending faults occur both north and south of a major crossfault. This cross fault has been traced beyond the Black Canyon area to the eastern edge of the mountains (Plate __________). In the mine area the vertical displacement on this fault is approximately 60 feet. There is no evidence of appreciable strike slip movement. The high-angle north-northwest trending faults north and south of the cross fault do not match. They apparently were not through going, but terminated at the cross fault. The resulting fault bounded blocks moved independently and as a result there are apparent reversals in the direction of relative displacement ~~on~~ at the cross fault.

The north-northwest trending faults may also terminate to the south along a north-northeast trending fault in Black Canyon. This could not be verified at the surface. One of the lower levels of the Black Canyon mine was extended south to a point below Black Canyon. There it encountered "bad ground" and was terminated. The "bad ground" occurred at the projected intersection of the vein and the Black Canyon fault.

All the known mineral deposits in the Black Canyon area are in narrow veins in open spaces along north-northwest trending faults or fault zones. The north-northwest faults were not all mineralized, and only the Black Canyon-Geranimo and Tower-Nancy veins were large enough to be profitably mined. With the exception of the Gloryana all the ore deposits are in the crystal tuff (Tx). The Gloryana pit is entirely within the tuff breccia (Ttb).

Manganese minerals occur in small amounts in scattered cavities in the crystal tuff, but are not present in the underlying rocks. The diamond drill hole at the Tower mine penetrated the crystal tuff and several of the underlying stratigraphic units. It intersected the Tower fault 700 feet below the base of the crystal tuff. Manganese minerals were not present at that intersection. It appears that the deposits donot continue below the base of the crystal tuff. Neither of the underground mines has reached the base of the crystal tuff, but the bottom level of the Black Canyon mine is within 100 feet of it.

Geronimo?

## Black Canyon-Gernaimo Deposit

The Black Canyon and Geranimo mines are in the same north-northwest trending mineralog~~ical~~ ized fault zone. The Black Canyon mine is on the east slope of a north trending ridge, the Geronimo is approximatdy 1000 feet north on the west side near the crest of the same ridge. Both mines are in the crystal tuff (Tx).

The Geronimo workings consist of a shallow pit 260 feet long and a 100 foot inclined shaft. Three trenches north of the main pit were dug on the assumed extension of the vein, but did not expose it. These trenches are in the tuff breccia (Ttb) and crystal rich, welded tuff (Twx). These units are stratigraphically above the crystal tuff, The crystal rich tuff at this locality is a coarse breccia made up of large clasts of the normal crystal rich tuff, a tuff matrix. It has many of the characteristics of a volcanic flow breccia.

The vein below the Geronimo pit was explored by several hundred feet of drifiting from the third level of the Black Canyon mine. Some ore was mined from this extension, but the zone of mineralization was irregular and narrow, and because of this no additional work was done (L. A. Goret, oral communication).

The Black Canyon deposit was discovered by L. A. Goret and was operated by him and Valente Aguilar from 1954 to 1969. The mine workings consist of eight levels approximately 50 feet apart. A ninth level was started but encountered water in amounts that could not be handled by the available equipment. It therefore was not completed (A. L. Goret, oral communication).

The ore in the Black Canyon mine fills lenticular open spaces along fissures in the main fault zone. The rock adjacent to the fissures is brecciated and is in part cemented by manganese minerals. This zone of brecciation may be as much as 50 feet wide, but little of it is ore. Ore shoots have been mined for approximately 1000 feet along the fault strike and down dip to a depth of 450 feet. The bottom level is in dense reddish brown highly welded crystal tuff (Txw). The rest of the workings are in the typical crystal tuff. The ore shoots vary in length, seldom are more than a few feet wide, and are irregularly distributed.

Much of the deposit above the bottom level in the Black Canyon mine has been removed and it is unlikely that appreciable ore is present below that level. As already stated, the manganese mineralization probably is limited to the crystal tuff, and the bottom level of the mine is within 100 feet of its base. The fault zone in the Geronimo claims has been explored at the surface and in an extension of the third level of the Black Canyon mine. From the exposed part of the vein on the Geronimo claims to the base of the crystal tuff is approximately 400 feet and from the north end of the Black Canyon mine to the east-northeast cross fault (see plate________) is 1000 feet. This part of the vein is unexplored, and although the available information is not encouraging, it is the most promising section for future development.

Tower-Nancy Deposit

The Tower-Nancy deposit is approximately 1200 feet east of the Blue Canyon-Geronimo vein and on the east slope of the same northwest trending rdige. The Tower mine is an open pit 1400 feet long, with an average width of 100 feet and a maximum depth of roughly 200 feet. The Nancy mine workings are all underground and consist of three levels approximately 50 feet apart. Access is through an adit at the first level. Lower levels are connected by gentle inclines.

The original Nancy tunnel appears to have been driven to explore the downward continuation of the vein exposed in the Tower pit and therefore was considered a part of the Tower operation. It was not mentioned by L. L. Farnhams in his 1959 report. In 1965 it consisted of approximately 300 feet drift in the Tower vein and 100 feet of drift that branched to the east along a probable extension of the Grand Canyon vein (see plate_______). During the initial development L. A. Goret and V. Aguilar extended the branch drift to 700 feet, but at the time the vein could not be profitably mined. Most of the production from the Nancy mine came from the Tower vein.

The Tower-Nancy vein like the Black Canyon and others in this area is made up of scattered ore shoots asmuch as 3 feet wide and up to 100 feet long. These shoots occur in sheared and brecciated crystal tuff along a north-northwest trending fault zone. Many of the open spaces between the breccia clasts are filled with manganese minerals but in general the amount was not enough to justify mining.

Between the bottom level of the Nancy mine and the bottom of the crystal tuff there are between 200 and 300 feet of unexplored vein. If the vein terminates at the northern cross fault and to the south at its projected intersection with the fault in Black Canyon the strike length of the unexplored part of the vein is roughly 1800 feet (see plate______). Exploration of the Grand Canyon vein is limited to the work done in the east branch tunnel of the Nancy mine and to a small pit and adit at the north near the main cross fault (see plate________). At both places the vein contained manganese minerals and some ore was mined. The strike distance between them is approximately 1600 feet. If development of the Tower-Nancy and Grand Canyon veins is considered in the future these sections of the veins should be tested. Although the Nancy and Grand Canyon veins appear to terminate at the cross-fault, the evidence is not conclusive and some testing in the crystal tuff north of the fault would be justified.

## Gloryana-Optimo deposit

The Gloryana and Optimo mines are in a northwest trending fault zone in the northeast section of the Black Canyon area (Plate____). The main Gloryana workings consist of an open pit 500 feet long, 60 feet wide and 20 to 30 feet deep. There are several small test pits in the area, and one shaft north of the north end of the main pit is still evident. At the surface this shaft is east of the ore zone. Two shallow shafts, reported by C. Barrett, within the main Gloryana pit have been obliterated.

The Optimo (Blue Gold) mine is approximately 500 feet northwest of the Gloryana and in the same mineralized fault zone. The portal of the Optimo is at the intersection of the mineralized zone and a well defined N20 to 25°W trending fault that dips 80 degrees west. This fault is not mineralized at the surface and has not been explored at depth.

The Optimo workings are reported to have consisted of two adit levels 250 feet and 300 feet long. A shaft near the portal connected with the lower level. Both levels were driven southeast and in the same mineralized zone.

The Gloryana and Optimo mines are in the same fault zone but are separated stratigraphically. The Gloryana is in the rhyolitic tuff breccia (Ttb) approximately 100 feet above the Optimo which is in the crystal tuff (Tx). There are no well defined veins or ore shoots exposed in the Gloryana pit. The ore came largely from a wide fault breccia that was partly cemented by manganese minerals and much black calcite. At places in the pit the manganese minerals have been brecciated and recemented by groundup tuff and fine-grained white calcite. Apparently there was movement along the fault after the mineralization. At the Optimo the ore is also a fault breccia cemented by manganese minerals and black calcite, but the breccia zone is narrow.

The grade of the ore from both the Gloryana and the Optimo was low, and their combined production is reported to have been about 2000 long tons.

There has been no exploration of the Gloryana-Optimo ore zone other than that related to actual mining. However, on the basis of the available geologic data its potential for future development appears good. The mineralized Gloryana-Optimo fault zone is exposed at the surface for approximately 1000 feet along its strike. The Optimo mine is at the upper contact of the crystal tuff(Tx) and this contact is probably less than 100 feet below the floor of the Gloryana pit. The crystal tuff in the Black Canyon area is between 400 and 500 feet thick (Plage________). Most of the manganese production from the Luis Lopez district has come from the crystal tuff. Hence, it is reasonable to expect that the Gloryana-Optimo fault zone is mineralized for at least a 1000 feet along its trike and probably to a depth of between 400 and 500 feet. This possibility should be tested if future development of the deposit is planned.

p173

| ① d(Å) | I | ② d(Å) | I | ③ d(Å) | I | ④ d(Å) | I |
|---|---|---|---|---|---|---|---|
| 7.55 | 20 | | | 9.37 | S | | |
| 6.91 | 100 | 6.[illegible] | 100 | 7.02 | S | 7.02 | 1 |
| 4.95 | 25 | [illegible] | 50 | 4.96 | MS | 4.98 | 2 |
| 4.07 | 10 | | | 4.15 | W | | |
| 3.46 | 25 | 3.45 | 5 | | | 3.48 | |
| 3.13 | 30 | 3.13 | 90 | 3.12 | S | 3.13 | 10 |
| 2.39 | 40 | 2.40 | 100 | 2.40 | W | 2.39 | 6 |
| 2.15 | 10+ | 2.14 | 40 | 2.15 | W | 2.16 | 4 |
| 1.93 | 10 | 1.95 | 5 | | | | |
| 1.83 | 15 | 1.82 | 20 | 1.84 | VW | 1.84 | 2 |
| | | 1.63 | 10 | 1.66 | VW | 1.65 | 1 |
| [illegible].56 | 10+ | 1.54 | 30 | 1.55 | VW | 1.54 | 2 |

① Insoluble residue from [illegible] [illegible] [illegible]

[illegible] [illegible] Analysis by C.W. Walker

② Cryptomelane, Sorem and Cameron, Econ Geol. v. 55, 278 (1960), ASTM 12-706

③ [illegible], [illegible], Econ. [illegible] v. 58, [illegible] (1963)

④ Hollandite, Hewett, Econ Geol, v. 66, 173 (1971)

Table —— X-ray diffraction data for cryptomelane and hollandite

(put at top)

# REFERENCES

Denny, C. S. (1940) Tertiary Geology of the San Acacia Area, New Mexico, Jour. Geol. vol. XLVIII, no. 1, p. 73-106.

Hewett, D. F. (1964) Veins of Hypogene Mn oxide Minerals in Southwestern United States, Bull. of the Soc. of Econ. Geol., vol. 59, no. 8, p. 1440

--------(1971) Coronadite-Modes of Occurrence and Origin, Bull. of theSoc. of Econ. Geology, vol. 66, no. 1, p. 167.

Jicha, H. L., Jr. (1956) Manganese deposits of Luiz Lopez district, Socorro County, N. Mex., Symposium on deposits of Manganese: International Geol. Cong., 20th, Mexico City 1956, vol. 3, p. 231-253.

Miesch, A. T., (1956) Geology of the Luiz Lopez Manganese district, Socorro County, New Mexico: New Mexico Bur. of Mines and Mineral Resources Circular 38.

Richmond, W. E. and Fleischer, M., (1942) Cryptomelane, a new name for the commonest of the psilomelane minerals, Am. Mineralogist, v. 27, p. 607-610.

Sanford, Allan R. (1965) An Instrumental Study of New Mexico Earthquakes, New Mexico Bur of Mines and Mineral Resources, Circular 78.

Sheridan, M. F. (1970) Fumarolic Mounds and Ridges of the Bishop Tuff, California, Geol. Soc. Am. Bull., vol. 81, no. 3, p. 851-868.

Smith, Robert L. (1960) Ash Flows, Geol. Soc. Am. Bull., vol. 71, no. 6, p. 795-842.

Weber, Robert H. (1971) K/Ar Ages of Tertiary Igneous Rocks in Central and Western New Mexico. Isochron/West, A Bull. of Isotopic Geochronology, No. 71-1, p. 33-45.

Analyses (Willard)

Dr. Gerald U. Greene
CONSULTANT
P. O. Box 681 -:- Phone (505) 835-1233
SOCORRO, NEW MEXICO 87801

January 15,1968

Mr. Jackie Smith,
New Mexico State Bureau of Mines,
Socorro,New Mexico.

Dear Sir; Re-Results on manganese samples.

| | | | | |
|---|---|---|---|---|
| T-1 Optimo | 1.06 | ounces silver / ton | 0.02 | oz/ton gold |
| G-1 (NOIBN) | o.68 | " | 0.01 | " |
| G-2 (NOIBN) | 0.68 | " | 0.01 | " |
| G-3 (NOTBN) | 0.20 | " | 0.ol | " |
| G-4 * | 3.30 | " | 0 | " |

The amount of manganese oxide was incorrectly estimated and the lead button only weighed 15 grams.For accurate results it is usually considered that the lead button should weigh 25 grams.For small amounts of gold and silver I have found accurate results will as small as a ten gram button.The results on the 15 gram button were - 3.30 ounces of silver per ton,gold - none.If any more assays are desired,G-4 should be rerun.

Accuracy- When the amount of gold present is 0.01 milligram,the accuracy of determination is well within a 2 per cent error;when the actual weight is less than 0.01 mg,an error of 25 per cent may be presentIn T-1 Optimo,the accuracy is within 2 % but the G series have a lesser degree of accuracy.

The samples were inquarted and two inquart blanks were run at the same time.Average loss of silver in the blanks was applied to the assays.Allowing for a slight difference in individual inquarts,the accuracy of these low silvers is well within 10 %. Where the silver is run alone and no inquarts are added,the accuracy is within 2 %.

Gerald U. Greene

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY
STATE BUREAU OF MINES AND MINERAL RESOURCES | SOCORRO, NEW MEXICO 87801

Max Willard

| Sample # | % Cu | % Pb | % Ba | % Zn | % Mn | % W |
|---|---|---|---|---|---|---|
| P-13 | .09 | 0.001 | 12.80 | 0.20 | 55.8 | 0.160 |
| P-14 | .07 | 0.038 | 14.80 | 0.24 | 56.7 | 0.166 |
| P-15 | .13 | 0.003 | 7.60 | 0.31 | 56.1 | 0.154 |
| P-16 | .06 | 0.002 | 5.00 | 0.08 | 56.9 | 0.064 |

L. Brandvold

|  | % Pb | % Ba | % Mo | % W | % Zn |
|---|---|---|---|---|---|
| P 9 | .053 | 12.4 | 0.084 | 0.37 | 0.053 |
| P 10 | 1.36 | 11.2 | 0.040 | 0 | 0.165 |
| P 11 | 2.02 | 9.6 | 0.112 | 0 | 0.141 |
| P 12 | 0.13 | 12.6 | 0.100 | 0.24 | 0.0497 |

|  | % Mn |
|---|---|
| P 9 | 54.5 ±1 |
| P 10 | 55.8 ±1 |
| P 11 | 56.0 ±1 |
| P 12 | 55.0 ±1 |

Mn Samples for Max E. Wallace.

| | | % Ba | % Pb | % Zn | % W | % Mo | % Ag |
|---|---|---|---|---|---|---|---|
| In: | 12-12-67 | | | | | .014 | |
| Out: | All but Ba & Ag. - 1-8-68 | | | | | .032 | |
| 3757 | P-1 | 8.18 | 1.07 | .026 | .247 | .014<br>~~.019~~ | |
| 3755 | P-2 Bursum | 10.68 | 2.35 | .143 | .116 | .032<br>~~.033~~ | |
| 3759 | P-3 Big Burro, Upper Pit | 13.15 | .006 | .338 | .221 | .019<br>~~.012~~ | |
| 3760 | P-4 " " Lower Pit | 11.75 | .042 | .293 | .160 | .028<br>~~.024~~ | |
| 3761 | P-6 Carmine pl., Grab | 13.[illegible]0 | 3.85 | .087 | .121 | .042<br>~~.027~~ | |
| 3762 | P-7 | | .022 | .455 | .198 | .024<br>~~.044~~ | |
| 3763 | P-8 | | .006 | .263 | .053 | .029<br>~~.032~~ | |
| 3764 | Bursum [illegible] | .91 | .216 | .365 | .018 | .011<br>~~.033~~ | |
| 3765 | N-1 Portal Nancy | 13.08 | .630 | .358 | .296 | .022<br>~~.010~~ | |
| 3766 | N-2 North drift | 19.63 | .645 | .435 | .348 | .020<br>~~.045~~ | |
| 3767 | N-3 | 11.[illegible] | .152 | .363 | .317 | .040<br>~~.023~~ | |
| 3768 | N-4 | 12.68 | .219 | .153 | .179 | .015 | |
| 3769 | N-5 | 12.28 | .500 | .200 | .150 | .023 | |
| 3770 | (B) P-5, Black Calcite | 0 | .038 | .106 | — | — | |

| | Cu | Co |
|---|---|---|
| P-1 | .023 | .020 |
| P-2 | .065 | .031 |
| P-3 | .060 | .057 |
| P-4 | .087 | .046 |
| P-6 | .013 | .006 |
| P-7 | .098 | .026 |
| P-8 ~~Bursum~~ | .023 | .705 |

| | Cu | Co. |
|---|---|---|
| Bursum | .075 | .002<br>~~.020~~ |
| N1 | .076 | .027<br>~~.034~~ |
| N2 | .058 | .026<br>~~.029~~ |
| N3 | .052 | .017<br>~~.046~~ |
| N4 | .017 | ND<br>~~.006~~ |
| N5 | .032 | ND<br>~~.026~~ |
| P5 (blackcalcite) | .0001 | ND |

## M. Willard. Mn minerals

Best values (we think!)

| | Ba | Pb | Fe | Cu | Zn | Ni | Co | PPM Ag | Sr | Mo WO3 |
|---|---|---|---|---|---|---|---|---|---|---|
| MCA-1 82 | 10.7 | 1.10 | 1.06 | .064<br>~~.062~~ | .27 | | | | .32 | .020 |
| OT-1 3 | 4.3 | 4.20 | | .012 | .31 | | | | —0 | |
| T3 4 | 13.[illegible] | 4.74 | | | | | | | | |
| T4 5 | 11.14 | 0.81 | | .033<br>~~.029~~ | .22 | | | | .105 | .027 |
| T5 6 | 9.16 | 1.70 | .039 | .013<br>~~.011~~ | .12 | | | | .080 | .015 |
| T6 SW 7 | 11.1 | 1.57 | | .023<br>~~.022~~ | .34 | | | | 0.30 | .012 |
| T6 NE 8 | 12.6 | 0.94 | | .015 | .62 | .0054 | — | .09 | | |
| T9 9 | 13.3 | .51 | | .030<br>~~.018~~ | .66 | .0095 | .056 | .02 | | |
| T10 1190 | 9.2 | 5.69 | | .013 | .23 | .0032 | — | .06 | | |
| T11 1 | 10.4 | 4.76 | | .016 | .22 | .0043 | .022 | .37 | | |
| T12 2 | 12.2 | 3.57 | | .012 | .28 | .0049 | .011 | .06 | .027 | |
| T13 3 | 10.9 | 3.86 | x0.29 | .016<br>~~.015~~ | .20 | .0049 | — | 15.60 | .030 | .004 |
| T14 4 | 10.6 | 5.03 | .045 | ~~.018~~<br>.012 | .06 | .0037 | .009 | [illegible] | .030 | .013 |
| T15 5 | 11.5 | 3.44 | .032 | .014<br>~~.012~~ | .05 | .0035 | .009 | .09 | .025 | .006 |
| T16 6 | 12.6 | 1.05 | .035<br>~~.031~~ | .013<br>~~.012~~ | .10 | .0020 | — | ND | .042 | .007<br>.058 |
| T17 7 | 11.5 | .62 | .034 | .013 | .06 | .0020 | — | | | |
| T18 8 | 11.9 | 1.56 | .024 | .027<br>~~.025~~ | .25 | .0060 | .022 | .01 | .041 | 0.002 |
| T19 9 | 14.4?<br>~~12.4~~ | .91 | .073 | .015 | .05 | .0043 | — | | | .064 |
| T20 1200 | 12.9 | .71 | .135 | .023<br>~~.036~~ | .13 | | — | ND | .030 | .005 |
| G1 1 | 10.7 | 2.53 | .091<br>~~.087~~ | .024<br>~~.021~~ | .02 | .014 | .020 | ND | .050 | .013 |
| G2 2 | 15.0 | .42 | .040<br>.040 | .030<br>~~.026~~ | .22 | .010 | .007 | ND. | .080 | .009 |
| G3 3 | 13.2 | 1.22 | .066<br>~~.044~~ | .029<br>~~.021~~ | .22 | .008 | .004 | | .060 | .016 |
| G4 4 | 10.1 | 1.64 | .060<br>~~.051~~ | .103<br>~~.015~~ | .29 | .011 | .055 | | .090 | .023<br>.010 |
| G5 5 | 12.3 | .74 | .086<br>~~.066~~ | .099<br>~~.085~~ | .11 | .027 | .029 | | .063 | .005 |
| T-1 845 | 5.30 | 12.30 | 1.64 | .076 | | | | | 0 | -.387 |
| T-7 846 | 2.80 | 1.53 | 4.20<br>4.45 | .020<br>.020 | .04 | | | | \ | .01 |
| T8 - 847 | 5.9 | .03 | 1.96 | .011 | | | | | | |

# Moly Assays

| Sample # | % Mo A.A. | Spec. | % Mo Colorimet |
|---|---|---|---|
| 1182 | 0.020 |  | 0.048 |
| 1185 | 0.027 | .044 | 0.109 |
| 1186 | 0.015 | .010 | 0.030 |
| 1187 | 0.012 | .016 | 0.026 |
| 1193 | 0.004 | .11 | 0.047 |
| 1194 | 0.013 | .024 | 0.09 |
| 1195 | 0.006 | .020 | 0.055 |
| 1196 | 0.007 | .018 | 0.022 |
| 1198 | 0.002 | .018 | 0.018 |
| 1200 | 0.0046 | .027 | 0.016 |
| 1201 | 0.013 | .061 | 0.043 |
| 1202 | 0.009 | .012 | 0.051 |
| 1203 | 0.016 | .022 | 0.112 |
| 1204 | 0.023 | .050 | 0.181 |
| 1205 | 0.0054 | .037 | 0.053 |

Elements; In addition to Mn + O

Bi [illegible]
Pb [illegible]
Fe 0
Cu [illegible]
Zn [illegible]
Ni [illegible]
Co [illegible]
W [illegible]
Mo [illegible]
Au [illegible]
Ag [illegible]
K [illegible]
As [illegible]
Sb
Tl
Sr [illegible]
Ba [illegible]
Mg [illegible]
Ca [illegible]
Na

# Lead Assay for Max Willard

Date In: April 12

Date Out: April 13

| Sample# |  | Description | % Pb |  |
|---|---|---|---|---|
| 845 | .04 | T1 | 11.51 | 13.75 |
| 846 |  | T7 | 1.24 | [illegible] |
| 847 | .037 | T8 | 2.95 | 3.75 |
| 848 |  | T13a | 0.10 |  |

Max's original list of figures; captions and #'s agree with text (RWE)

Fig. 1 Principal Mines and Prospects

2 Half-beads and rosettes of manganese oxide in cavities in the crystal tuff.

3 K-feldspar, sericite alteration along cleavage planes in plagioclase phenocryst from the porphyritic andesite. (X nicols) (40X).

4 Tuff breccia (Ttb) at the Gloryana pit. Large clasts are vesicular basalt.

micrograph

5 Scanning electron microscope photo of quartz and sanidine in altered limestone(?) xenolith from the tuff breccia (Ttb). X 260

6 Rounded and deeply embayed quartz grain from the Red Canyon latite intrusive, X ___.

7 Microfractures in quartz grains from Red Canyon latite intrusive. X ___?

8 Synoptic diagram of the structural development of the Chupadera Mountains.

Fig 9 Brecciated crystal tuff exposed in the MCA pit.

(a) Breccia fragments have been moved about, and are randomly oriented.

(b) The rock is shattered but the fragments are only slightly dissplased.

10 Scarp of the Western boundary fault at the north end of the Chupadera Mountains

11 Fault pattern in the northern Chupader Mountains

12 Specimen of reniform ore minerls from the vein at the Tower Mine

13. Polished specimen of the breccia are from the MCA mine. Bright metallic layers arond breccia fragment are manganese oxide, larger openspaces are filled with calcite.

14 Plumose barite from vein southeast of the Tower mine. The dark color at base of plumes is due to disseminated iron oxide.

Fig 15 Coarsely crystaline black, white and clear calcite from vein in the MCA pit.

16 Banded amber to white calcite cut by veinlet of "black calcite".

17 Microcrystaline cryptomelane concentrated along growth planes in "black calcite".

18 Cocklebur-like aggregates of cryptomelane in "black calcite"

19 Brecciated manganese mineral cemented by white finely crystaline calcite.

20 Polished specimen of banded manganese ore from the Tower mine.

21 Observed variations in degree of crystallization and crystal orientation that produce reflection banding.

22 Free standing fiberous manganese minerals, locally called "rat hair." Sample is from the Nancy Mine. X2

Frontispiece (air photo)
Northern Chupadera Mtns

Plate 1 Geologic Map of the Northern Chupadera Mountains.
2 Geology of the Tower-Black Canyon Area

3 Geologic Section Parallel Diamond Drill Hole, Tower Mine

Table 1 X-ray Diffraction Data for Cryptomelane
and Hollandite

note: these fig captions do not agree w. Willards text

Luis Lopez District
OF 186
M. E. Willard 1973

1. Photo-size negative of contour map - same as #33.
2. Tunnel sketch.
3. Nancy - tunnel pace and compass (fast) sketch.
4. Tunnel sketches - 3 sheets - Geronimo, Nancy, Black Canyon extension.
5. Geologic and mine map of area near Red Canyon same as #6, #7 (on vellum).
6. Map of mine area near Red Canyon, scale 1" = 200', contour interval 20'.
7. Contour and mine map of area near Red Canyon - same as #6 and base of #9.
8. Map showing the distribution of accessory elements in ore minerals of the Black Canyon area; shows Optima, Gloryana, Tower, Nancy, and Geronimo mines and Black Canyon shaft.
9. Map showing the distribution of accessory elements in ore minerals in an area near Red Canyon (unlabled).
10. Outline sketch of Tower Mining Company mine, Luis Lopez manganese district, Socorro Co., N.M. Showing the location of samples taken for assay labled by author as figure 3.
11. Map of the Nancy mine, 3-18-69, scale 1" = 50' (blue print copy).
12. Original of #11.
13. Geologic map, location not stated, contour interval 20'; map is a field copy, folded and torn.
14. Map of area between Socorro Canyon and Red Canyon from NMBM&MR Circular 38, Plate 1, with overlay showing sample

locations and numbers.

15. Bottom half of #14, geologic map and sections of the Luis Lopez manganese district, Socorro Co., N.M.
16. Overlay of position X's, part of T. 4 S., R. 1 W., fits over map #14.
17. Blue print copy of base map of part of the Luis Lopez district, same as #18, #20, shows location of one mine highlighted 17b-original of #17.
18. Geologic map of the Tower area, Luis Lopez dist., Socorro Co., N.M. Covers the same area as #20 but shows slightly different geology.
19. Drafted version of map #18 and a separate sheet of map explanations. Map titled by author: Plate 2, Geology of the Tower-Black Canyon mine (and Surface Geology in the Black Canyon Area).
20. Geologic map and sections of part of the Luis Lopez manganese district, Socorro County, N.M.; shows parts of T. 4 S., R. 1 W., and T. 4 S., R. 2 W.
21. Geologic map and section of the Tower manganese mine, Luis Lopez district, Socorro County, New Mexico. Contour interval 10'; labled by author as figure 2.
22. Cross section sketch through the Tower Mining Co. pit.
23. Cross section; shows projections of Black Canyon, Geronimo and Nancy mines.
24. Stratigraphic columns showing correlation between 3 areas; areas are not labled.
25. Idealized cross section from S to N; area not labled.

26. Geologic map overlay of area between Black Mesa and Red Canyon; over aerial photo GS-VMA 3-146 3-7-56.
27. Aerial photo DRA-7-151 (5-15-52); shows area between Black Mesa and Red Canyon. Partial geologic map drawn in.
28. Aerial photo DRA-7-153 (5-15-52); shows area south of Red Canyon.
29. Aerial photo DRA-7-153 (5-15-52); same as #28.
30. Aerial photo DRA-7-150 (5-15-52); shows Socorro Canyon, sketches of faults in southern portion of photo.
31. Aerial photo GS-VMA 3-147, 3-7-56; shows area of Socorro Canyon, contains a partial map of the geology, (on back-project 89, 273 Socorro 7½ SW corner).
32. Negative of contour map of Luis Lopez district.
33. Contour map of the Luis Lopez district with geologic map overlay.

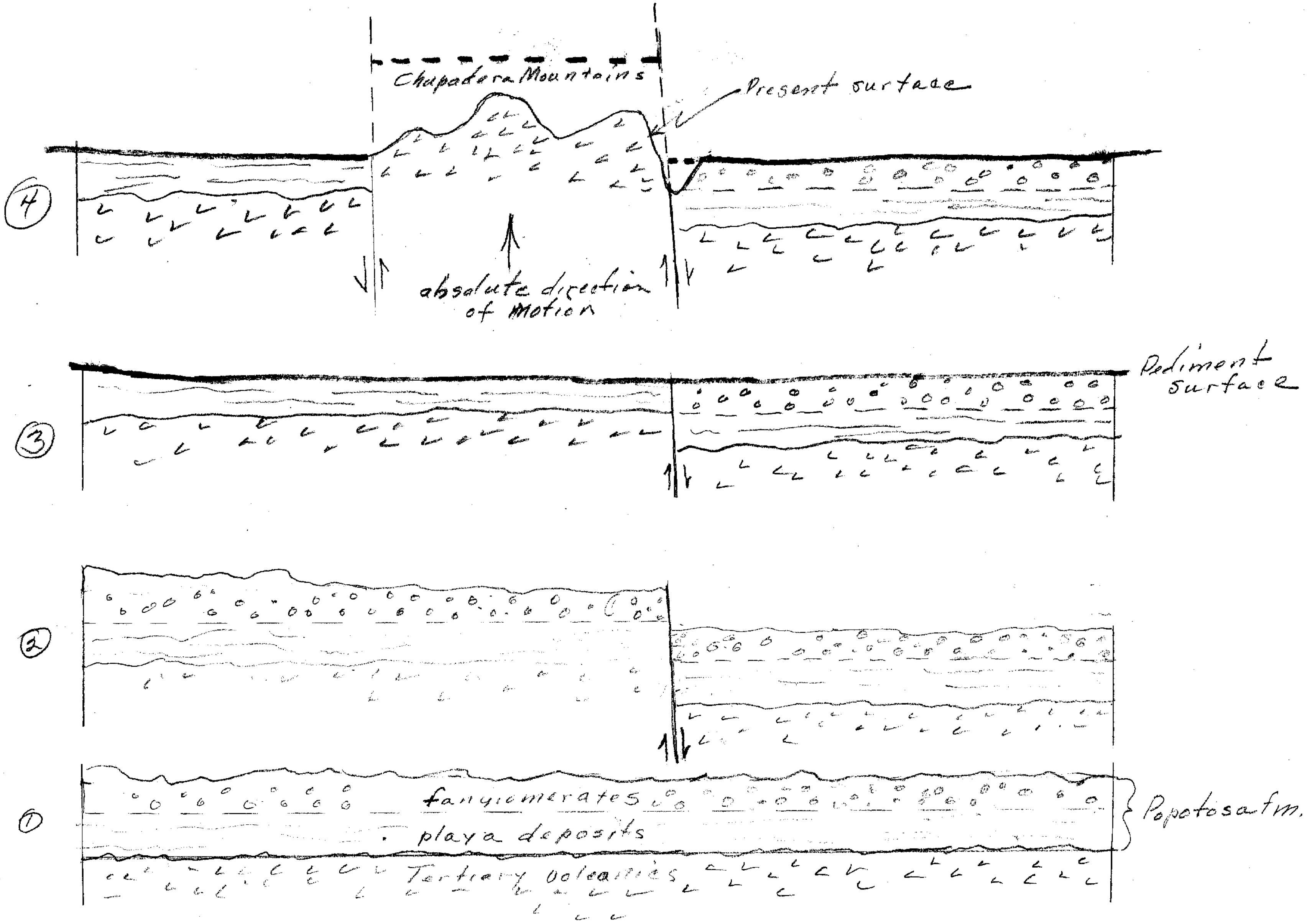


Fig. 8 Synoptic diagram of the structural development of the Chupadera Mountains.

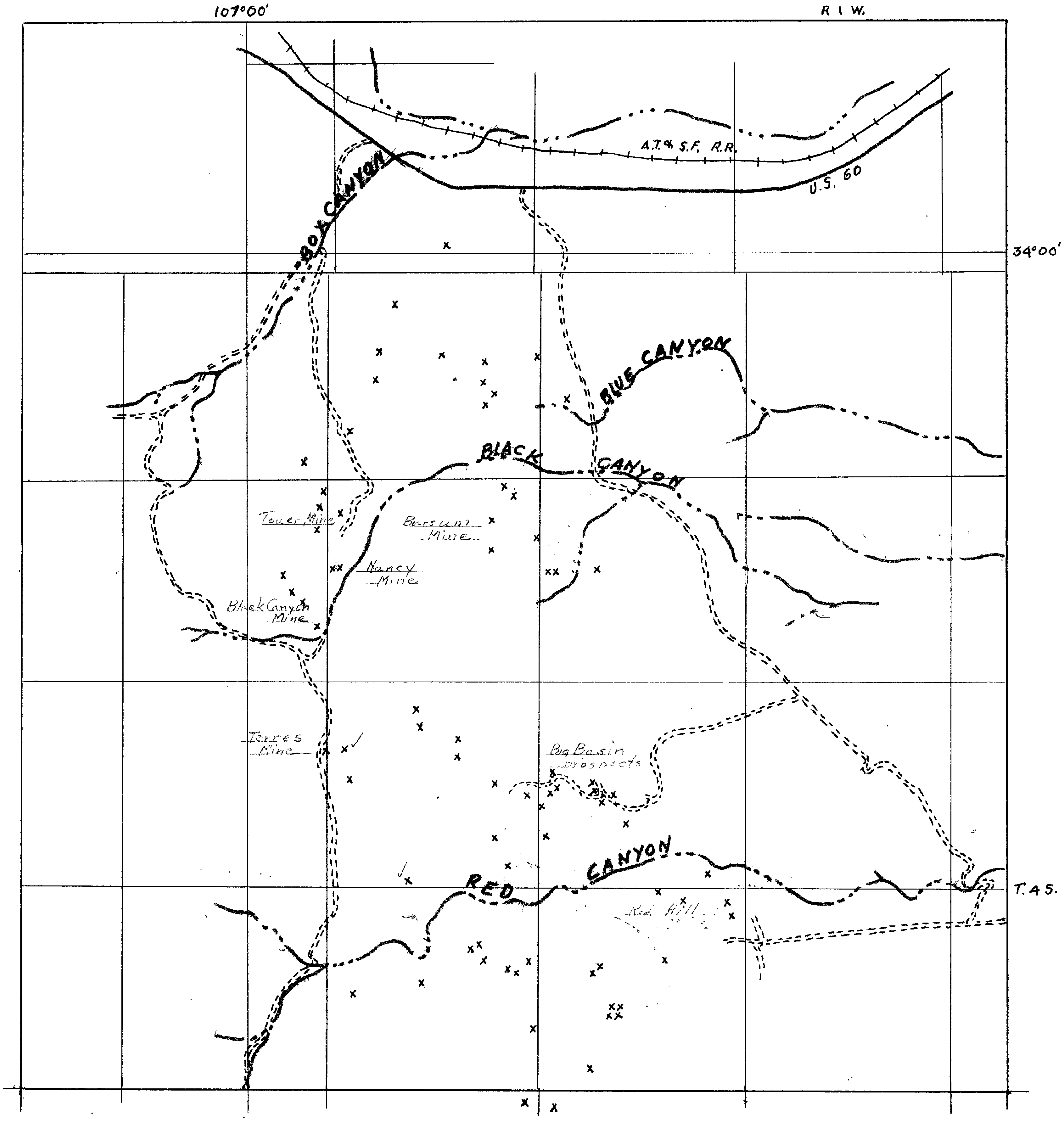


Fig. 9 Mines and Prospects of Luis Lopez District.