NO. 11

ESTADOS UNIDOS MEXICANOS

REPORT ON GEOLOGICAL SURVEY OF THE COAHUILA AREA, NORTHERN MEXICO

(CONSOLIDATED REPORT)

FEBRUARY 1979

METAL MINING AGENCY OF JAPAN
JAPAN INTERNATIONAL COOPERATION AGENCY
GOVERNMENT OF JAPAN

PREFACE

The Government of Japan, in response to the request of the Government of Estados Unidos Mexicanos, decided to conduct the Cooperative Mineral Exploration Project in the Coahuila area, northern Mexico, and has entrusted its execution to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

The survey started in 1975 has been accomplished under close collaboration with el Consejo de Recursos Minerales.

This report hereby summarizes the outcomes of the project obtained in four years.

We wish to express our heartfelt gratitude to the Government of Estados Unidos Mexicanos, el Consejo de Recursos Minerales and other authorities concerned for their kind cooperation and support extended to the survey team.

February 1979

Shinsaku Hogen
President
Japan International Cooperation Agency

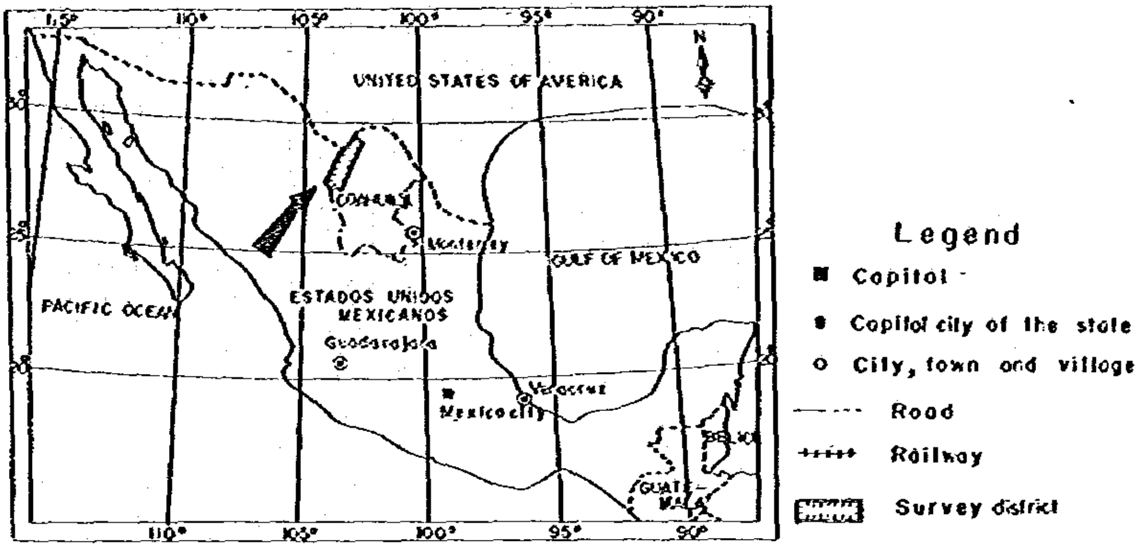
Masayuki Nishiie
President
Metal Mining Agency of Japan

LANDSAT Pseudo-Natural Color Composite Image of The Project Region, Northern Coahuila, Mexico

Scale 1:1,000,000

0 50 100km

Fig. 1 LOCATION MAP OF THE PROJECT DISTRICT



ACCESSIBILITY MAP

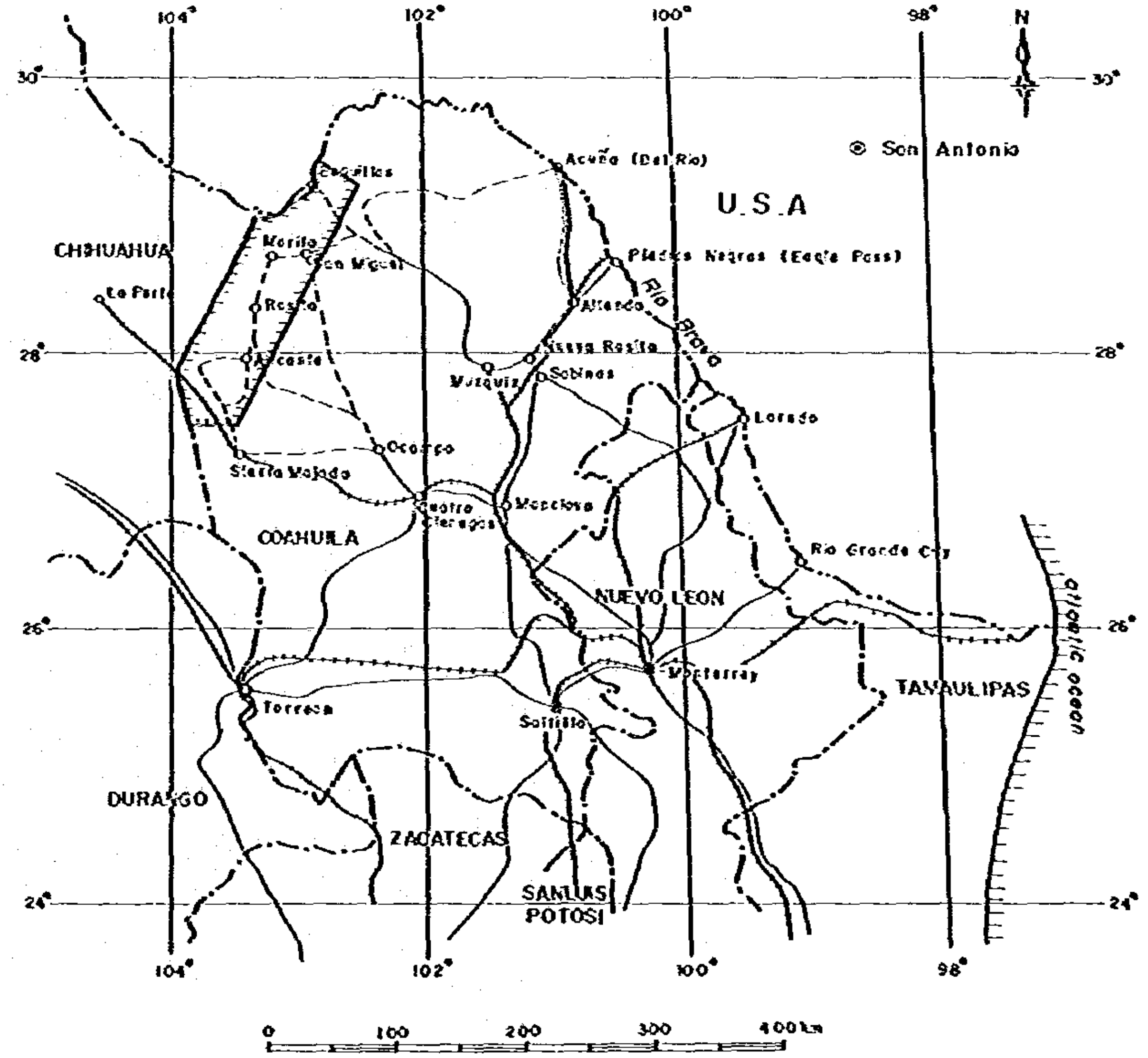
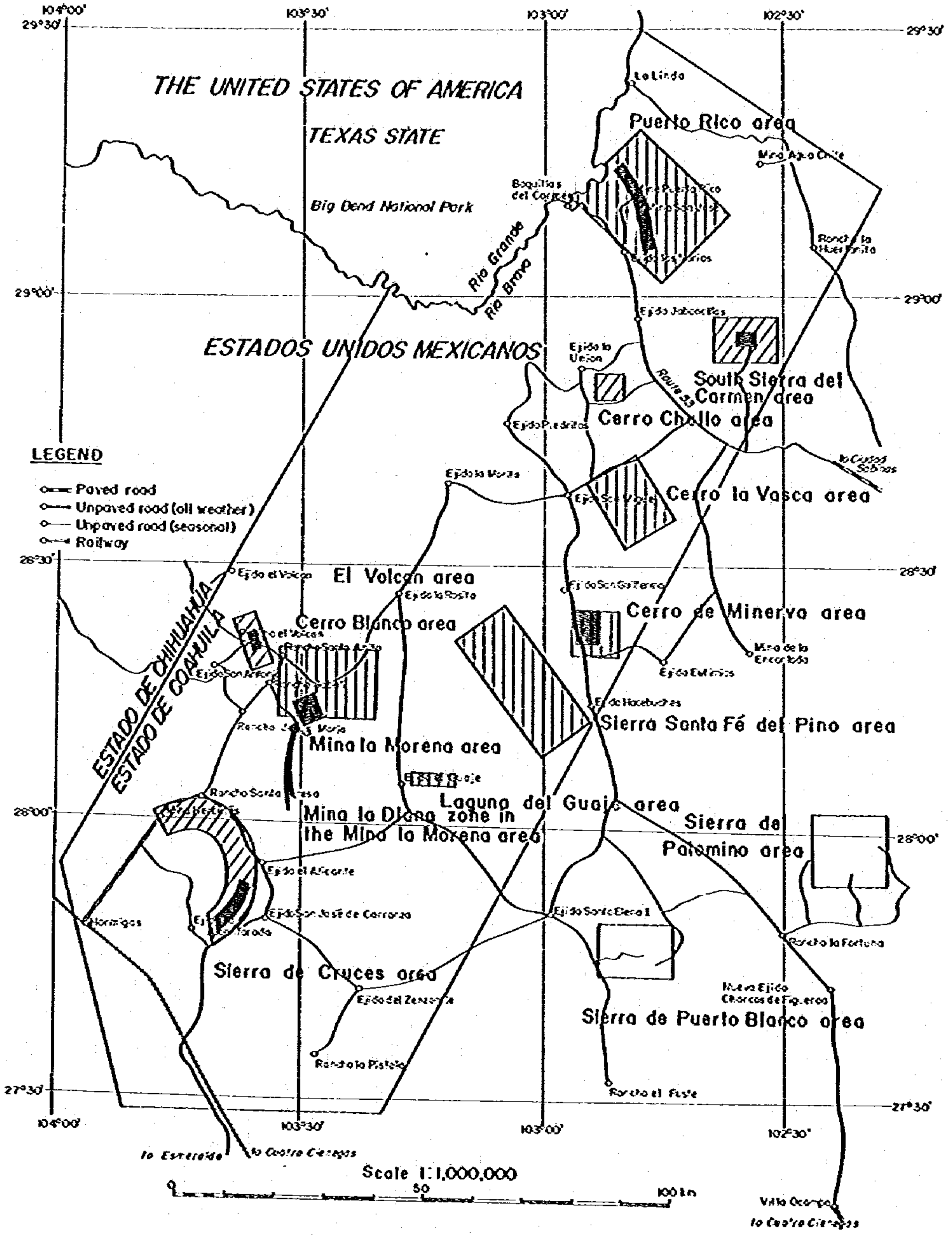


Fig. 2 LOCATION MAP OF THE SURVEY AREAS



LEGEND

PHASE I AND II SURVEY (1975, 1976)

- Regional survey district
- Semi-detailed survey areas:
  - Puerto Rico area
  - Cerro la Vasca area
  - Cerro de Minerva area
  - Sierra Santa Fé del Pino area
  - Cerro Blanco area
  - Laguna del Guaje area

PHASE III SURVEY (1977)

- Reconnaissance survey areas:
  - Sierra del Palomino area
  - Sierra de Puerto Blanco area
- Semi-detailed survey areas:
  - South Sierra del Carmen area
  - Cerro Chalio area
  - El Volcan area
  - Sierra de Cruces area
- Detailed survey areas:
  - Puerto Rico area
  - South Sierra del Carmen area
  - Cerro de Minerva area
  - El Volcan area
  - Mina la Morena area
  - Sierra de Cruces area

PHASE IV (1978)

- Highly detailed survey zone (Mina la Diana zone in the Mina la Morena area only)

SUMMARY

(1) Outline of the survey

The primary purpose of this project was to obtain the basic data for exploration and development of mineral resources in the target district of 16,000 square kilometers in Coahuila State, northern Mexico as the joint project of both governments of Japan and Estados Unidos Mexicanos.

The project district is located in the northwestern part of the State of Coahuila of northern Mexico, and confined to the north by the Rio Grande River, flowing eastward along the American border, and to the west by the border with the State of Chihuahua.

The district is rectangular in shape extending to NE-SW with E-W width of about 80 km and N-S length of about 200 km.

The topography of the district is characterized by the mountain ranges composed mainly of Cretaceous sedimentary rocks extending in NNW-SSE direction, plateau-like mountain blocks composed of Tertiary igneous rocks, prominent hills in the plain which are composed of Tertiary intrusive rocks and semi-desert peneplain underlain by Quaternary sediments.

The survey was conducted for four years from fiscal 1975 to 1978. It was initiated by various kinds of regional survey including aeromagnetic survey, LANDSAT data analysis, photogeological interpretation, regional geological survey, and regional geochemical survey.

The surveys in the middle stage consit of semi-detailed and detailed surveys of geology and geochemistry, geophysical survey, and diamond drilling. The results of these surveys were synthetically examined to compare and evaluate the potentiality of the areas.

As the result, the recrystallized zone of limestone in Mina la Morena area was selected for the target of exploration in the final fiscal year.

The survey of the final phase comprises detailed geological survey, electric survey of IP method, and diamond drilling, which resulted in the confirmation of the occurrence of high-temperature hydrothermal vein-type silver-bearing copper ore deposits (partly manto-type, irregular massive-type). Assay result showed about 1 g/T of gold, 50~several hundred g/T of silver, and several percent of copper. Lead and zinc were generally small in amount.

(2) Survey method

1. LANDSAT data analysis

LANDSAT data analysis consists of analog analysis with 70 mm film image and digital analysis with CCT.

In analog analysis, interpretation of geological unit by pseudo-natural color image and interpretation of geological structure by lineament analysis on edge-enhanced image were carried out.

In digital analysis, descrimination of correspondence between multi-spectral data of any given point and of training samples which reflects known geologic object and known ore deposit, were attempted.

As the result of analog analysis, deep-seated intrusive rocks and tectonic lines could have been best identified by lineament analysis. However, the descrimination of geological units in digital analysis can hardly be said to be useful enough.

2. Photogeological interpretation

Prior to surface geological survey, photogeological interpretation of the whole survey district was carried out. Thin vegetation and good correspondence between geology and topography of the district led to favorable result. Especially in the Cretaceous sedimentary rocks, the banding patterns constituted by the exposure lines of the beds and their boundaries were distinctly shown on the poto-graphs, which made ready to trace these features on the photographs. As the result of interpretation, it was made distinct that the folded mountain ranges composed of Cretaceous system extending in the direction of NNW-SSE which were characterized by asymmetric

anticlinoria with axes of the same direction. Thus, it can be said that the photogeological interpretation made great contribution as the guide to surface geological survey.

3. Geochemical survey

Geochemical survey was carried out in Phase II and Phase III.

The survey in Phase II consists of regional survey of the whole district, semi-detailed survey in some parts of the district by stream sediments samples, and detailed survey by soil samples in limited zones.

The indicator elements were Cu, Pb, Zn, Ag, and F in Phase II, while in Phase III, F was ruled out because it became clear that it did not sensitively reflect the mineralization and the alteration.

As the result of regional survey, nine geochemical anomaly zones were finally selected as promising.

Following the regional survey, these nine geochemical anomaly zones were further investigated into their scale, distribution and combination of indicator elements in detail by semi-detailed and detailed survey.

These geochemical data made great contribution as a basic data for selection of target areas for further investigation.

4. Geophysical survey

Geophysical surveys of the district were carried out as follows:

Phase I ... Aeromagnetic survey of the whole district.

Phase III ... Electric survey of IP method and electromagnetic survey of TURAM method in Puerto Rico area.
Ground magnetic survey in the Sierra de Cruces area.

Phase IV ... Electric survey of IP method in Mina la Morena area.

(a) Aeromagnetic survey

Flight line spacing was 1 km and total length of survey line was 19,100 line-kilometers.

As the result of this survey, a number of magnetic anomalies were detected. Most of the magnetic rocks which caused these anomalies were basic to intermediate igneous rocks.

(b) Surveys in Puerto Rico area in Phase III

Electric survey of IP method was carried out with line spacing of 200 m and total length of 20 line-kilometers. As the result of this survey, geological structure of the basement which is composed of Palaeozoic crystalline schists could be inferred.

Electromagnetic survey of TURAM method was carried out in the same area of IP method, with line-spacing of 100 m and total length of 40 line-kilometers.

As the result, electromagnetic anomalies which is considered to be closely associated with a number of mineralized zones of lead and zinc distributed in the area, were detected.

(c) Ground magnetic survey in the Sierra de Cruces area in Phase III

The survey was conducted at the eastern periphery of the intrusive rocks which consist the Sierra de Cruces mountain mass with total survey length of 45.5 line-kilometers. As the result, the distribution of many magnetic bodies were made certain, some of which were assumed to be iron ore deposit.

(d) Electric survey of IP method in Mina la Morena area in Phase IV

As a link of detailed surveys in Mina la Morena area in the final phase, IP survey was carried out with line spacing of 100 m and total length of 34.9 line-kilometers.

The result of survey showed a lot of weak IP anomalies.

Some anomalies, however, which are located in higher apparent resistivity zones in the recrystallized zone of limestone are considered to be related with mineralization.

5. Diamond drilling

Drilling was carried out in Puerto Rico area in Phase III and in Mina la Morena area in Phase IV.

In Puerto Rico area, three holes were drilled with a total length of 600 m in order to confirm the mineralization in the Las Norias tectonic zone. In Mina la Morena area, five holes were drilled with a total length of 1240.90 m in order to investigate the mineralization in thermal metamorphic zone of the Aurora limestone and to confirm the deep-seated intrusive igneous rocks.

As the result, important data which will serve to solve the character of the Las Norias fault were obtained, and it was made clear that the fault is one of the principal elements to control the mineralization in Puerto Rico area.

In Mina la Morena area, four holes including M1, M2, M3 and M5 intersected ore deposits rich in copper and silver, and especially in two holes of M2 and M5, primary sulfide ores were observed in part of the core, which served an important information to solve the character of mineralization. However, none of the holes intersected the concealed igneous rocks assumed to occur in the depths, which in turn proved that the intrusive rock would be seated deeper than anticipated.

(3) Survey results

1. Geology

The project district is situated in the northeastern part of the Mexican geosyncline which was brought about as miogeosyncline after the Nevadan orogeny. Cretaceous sedimentary rocks with prevailing calcareous sediments are widely distributed overlying possibly Palaeozoic crystalline schists. Tertiary volcanic rocks are distributed in some parts of the district overlying these sedimentary sequencies.

1.1 Stratigraphy

Geology of the survey areas can be classified into basement considered to be of Paleozoic, Cretaceous system composed principally of calcareous sedimentary rocks, and Tertiary system composed principally of volcanic rocks. The Cretaceous system is roughly grouped into the lower and the upper. The lower Cretaceous system

consists of the Coahuila series (Puerto Rico and Cupido formations) and the Comanche series (La Peña, Glen Rose, Telephone Canyon, Del Carmen, Sue Peaks and Santa Elena formations). Lower part of the upper Cretaceous system belongs to the upper part of the Comanche series (Del Rio and Buda formations), while the main part pertains to the Gulf series (Boquillas, San Vicente and Pen formations). In the southern half of the survey district, there are found the Aurora formation, contemporaneous heterotopic facies to the Glen Rose, Telephone Canyon and Del Carmen formations of the lower Cretaceous system. In addition, some parts of the Aurora formation is contemporaneous to the Sue Peaks and Santa Elena formations in the El Volcan and Sierra del Palomino areas.

The Tertiary system which is mostly composed of volcanic rocks with a small amount of tuffaceous sandstone is mainly distributed in the southern part of the Sierra del Carmen, the Sierra de Hechiceros and its surrounding area, and the southern part of the district from the Sierra de San José to the Sierra de San Antonio, and is roughly classified into three groups, the south Sierra del Carmen volcanics, the Sierra de Hechiceros volcanics and the Sierra de San José volcanics.

The Quaternary system is mainly composed of sand and gravel, and distributed widely in desert-like lowlands and intermontane lowlands. In bolsons such as the Laguna del Guaje, etc., some evapolites with fine clastic material are recognized.

1.2 Intrusive rocks

Based on the relation to main fold movement, intrusive rocks in the district are classified into three principal types such as (A) intrusive rocks before main folding stage, (B) intrusive rocks during main folding stage, and (C) intrusive rocks after main folding stage, and these are further subdivided according to occurrence, lithofacies, K-Ar age, and interrelation of intrusion for each other.

(A) Intrusive rocks before main folding stage

(A)-1 Hypabyssal intrusive rocks due to preceding igneous activity

The intrusive rocks which fall in this category are characteristic in showing the occurrence of sill, and consist of dolerite, rhyolite and granophyre. Though some small bodies are found in pelitic rocks of the lower Cretaceous, the rocks of this type intrude generally the upper Cretaceous, particularly in thickly accumulated parts of it. These are penetrated by (A)-2, and considered to be introduced by igneous activity at the later stage of the geosynclinal process. No significant metallization is recognized.

(A)-2 Plutonic rocks from late Cretaceous to early Tertiary

Although the intrusive rocks of this type are associated with thermal metamorphic (recrystallization) zones in the adjacent areas, skarnization is generally weak, therefore, it is conceivable that they were introduced so-called in "dry" condition. These rocks are accompanied with some mineralization of lead, zinc, and iron, but large-scale contact-type deposits have not been found. K-Ar age is $65 \sim 67 \times 10^6$ years.

(B) Intrusive rocks during main folding stage

The period of folding in the Laramide orogeny is considered to be between 45×10^6 years (middle Eocene) and 35×10^6 years (early Oligocene). During this period, intrusive igneous activites were taken place mainly in the Sierra del Carmen area, and massive to irregular pod-shaped fluorite deposits of significant scale were formed in some parts of the district.

(C) Intrusive rocks after main folding stage

(C)-1 Intrusive rocks from Oliogocene to Miocene

Quartz syenite porphry ($27 \sim 27.2 \times 10^6$ years, late Oligocene) in the Sierra del Carmen area and altered rhyolite of dike-form in the Sierra de Cruces area are included in this category. The former is accompanied by thermal metamorphic zone associated with skarn minerals surrounding the rock, within which gold and silver

mineralization is observed. The latter is presumed to be produced with relation to the activity of rhyolite of the Sierra de San José volcanics.

(C)-2 Intrusive rocks from late Miocene to Pliocene

The Sierra de Cruces complex (5.2×10^6 years, late Miocene) and granite porphyry in the El Volcan area (4.2×10^6 years, Pliocene) fall in this category, which are characterized by remarkable thermal metamorphic zones and skarn zones produced around the igneous bodies. The plutonic rocks which are presumed to be seated in depth in areas such as Mina la Morena and Picacho may belong to this type.

These rocks are composed of acidic intrusive rocks and accompanied by predominant iron deposits, manganese deposits, and significant copper showings, which build up the most preponderant concentration of base metals in the project district.

2. Geologic Structure

The project district and its surrounding areas were put the influence of the Laramide orogeny which took place from late Cretaceous to Tertiary following the subsidence which is shown in the sedimentation of the thick Cretaceous calcareous sediments within the Mexican geosyncline. During the orogeny, foldings characterized by asymmetrical features and fold-faults together with the Las Norias tectonic zone bounding the eastern limit of the folded zone were produced. From the results of K-Ar dating and the influence of folding afforded to the rock bodies, the period of the folding caused by the orogenic movement is considered to be in the range between 45×10^6 and 35×10^6 years.

The northern part of the district was under the influence of the Texas zone represented by brisk igneous activites, which resulted in formation of folding of short-wave length and emplacement of numerous intrusive rocks.

In the late Tertiary, the whole district underwent vigorous acidic igneous activities. Normal faults were formed possibly by tensional

stresses, and it is also likely that pre-existed faults were re-activated.

Based on these tectonic elements, the project district and its surrounding areas were divided into five zones such as Marathon zone, Sierra del Carmen zone, Rio Bravo folded zone, Pino-Monclova zone, and Mula-Mojada zone.

3. Ore Deposit

A number of ore deposits and mineral showings distributed in the district are classified based on their principal ore minerals into fluorite deposit, silver-bearing copper, lead and zinc deposit, gold and silver deposit, and iron deposit.

3.1 Fluorite deposit

Most of the fluorite deposits are concentrated in Sierra del Carmen zone area and Rio Bravo folded zone on the north of the Los Alazanes tectonic line, though some small showings are distributed in the vicinity of the Cerro la Vasca and El Volcan areas in southern part of the district. Fluorite is also accompanied as gangue mineral in many deposits except iron deposits.

Fluorite deposits are classified into following three types based on their shape:

(A) Massive ~ irregular pod-shaped deposit

Most of the fluorite deposits which had been substantially operated belong to this category, and the size of unit ore body is generally large. The ore deposits are mostly associated with doleritic to rhyolitic intrusives of alkaline rock series and partly with adamellite to monzonite, and occur in limestone as irregular masses along the contacts between intrusive rocks and limestone beds. Calcite is the principal gangue mineral.

(B) Manto-type deposit

The fluorite deposits of this type are generally small, and of manto or network preferentially localized at the top of the Santa

Elena formation. It is an important feature that there is no significant volcanic activity in the area of distribution of this type of deposits.

(C) Vein-type deposit

The deposits of Lea and La India in El Volcan area are of this type of fluorite deposits, which are formed in echelon-shaped silicified parts in relatively persistent fault zones. Deposits of this type are found in the Pen and San Vicente formations, which are far upper horizons compared with those of other types. The age of mineralization is inferred to be Pliocene or later, which is also far younger than others.

3.2 Silver-bearing copper, lead and zinc deposit

The ore deposits are classified based on their occurrences into type a: vein-type deposit and type b: contact-type deposit. The latter is subdivided into type b-1: the deposit related with pre-folding intrusive rocks and type b-2: the deposit related with post-folding intrusive rocks.

Type a Vein-type silver-bearing copper, lead and zinc deposit

All ore deposits and showings in Puerto Rico area, Collan deposit, La Morena deposit, El Refugio deposit, and deposits in the adjoining area of the Santa Elena anticline belong to this type. These deposits are located in large-scale geological structures such as anticlines and fold faults brought by the Laramide orogeny, and Las Norias tectonic zone. Mineralization took place after the orogenic movement, and may have continued up to Pliocene. Except for Collan and La Diana deposits formed in the Aurora formation, all other deposits are found in the Cupido formation, and most of the principal deposits are in the Cupido formation.

Type b-1 Contact-type silver-bearing copper, lead and zinc deposit of pre-folding

The deposits and mineral showings in and around the Cerro de Minerva area fall in this type, which are considered to be brought by

intrusive rocks of (A)-2 type (described above) possively intruding in so-called "dry" condition. They are small in scale and of low grade, and it can be said that the economic value of this type is very low.

Type b-2 Contact-type silver-bearing copper, lead and zinc deposit of post-folding

The deposits such as El Volcan, La Diana, Libertad, and Quebrada belong to this type. These deposits are considered to be brought by plutonic intrusive rocks which were classified as C-2 type (described above). The rocks are mostly acidic, and accompanied with skarn zones and recrystallized zones surrounding them. The deposits of this type have hardly been explored in this district, especially in the case that the intrusive rocks are seated in depth. It is considered that the exploration will be needed to investigate the potentiality of ore deposition systematically in and around such intrusive rocks.

3.3 Gold and silver deposit

Deposits of this type are distributed only in the South Sierra del Carmen area, which includes such known ore deposits as Fronteriza, Teresita, and Juarez. These deposits are considered to have been formed with relation to quartz syenite porphyry of (C)-1 type described before, being embedded in skarn zones and recrystallized zones adjacent to the intrusive rocks. The deposits so far discovered are relatively small in scale and generally low in grade. All these are low in economic importance.

3.4 Iron deposit

The deposits of this type alone have been explored and developed systematically and extensively in the project district.

Iron deposit in the district are classified into a) orthomagmatic and b) contact-type. Operating ore deposits in the Sierra de Cruces area are of a-type, while some small-scale ones of b-type are found in the Cerro de Minerva and Cerro la Vasca areas.

As described hereto, various kinds of ore deposits are distributed in the district. After comprehensive evaluation for selecting potential ore occurrence in the district putting all the data and information obtained by the third phase together, the recrystallized zone of limestone in Mina la Morena area was selected with first priority for the targets of exploration in the final phase of this project.

3.5 Ore deposits in and around Mina la Diana in Mina la Morena area

The surveyed area is located in the central part of the Sierra la Morena, and the target of survey was a recrystallized zone of limestone approximately elliptical in shape having long axis of about 2.4 km and short axis of about 1.5 km which extends in the direction of NE-SW, in which an unusual topography of depressed low land was found.

The recrystallized limestone has a core of saccharoidal limestone (1.7 km x 1.1 km) surrounded by a halo of microcrystalline limestone with the width of 80 m ~ 400 m on the surface. In some part of the saccharoidal limestone, veins and porphyroblastic large crystal of garnet are observed. It is also associated with wollastonite and actinolite, and silicification is commonly observed.

Mineralized zones are divided into six groups according to their localities. The most typical mineralized zone located at the center of the area is concentrated by fifteen hematite-calcite-quartz veins having width of about 150 m and length of about 350 m. While most of these veins have steep dip and similar strike, some cross-veins and manto-type bodies are also observed.

Most of the single veins are several dozen centimeters in width and several dozen meters in length, however, some larger veins were traced for the length up to 300 m having the width of several meters.

Ore minerals observed on the outcrop are iron oxide minerals associated with green copper minerals. Under the microscope, hematite, cuprite, tenorite, native copper, and conichalcite are observed. Gangue minerals are calcite, quartz, fluorite, and gypsum. Garnet,

wollastonite, and actinolite are observed as accessory minerals.

In the core of diamond drill holes carried out in the mineralized zone, beside oxide ore minerals, primary sulfide ore such as pyrite, pyrrhotite, chalcopyrite, tetrahedrite, acanthite, polybasite and kobellite, and some silver halides such as cerargyrite and bromyrite are found.

The grades of these ores are in the order of 1 g/T of Au, from several dozen to several hundred g/T of Ag, and several percent of Cu. Lead and zinc are small in content such as 0.0n% and 0.n% respectively.

These ore deposits tend to be predominantly developed in the depths and the Cupido formation is the most favorable ore horizon in this district, it is considered that the future exploration should be directed to the confirmation of the lower extension of main mineralized zones to the horizon of the Cupido formation.

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Attached Sheet

PART I INTRODUCTION

This report is a consolidated report which was compiled from the annual reports on basic investigation of mineral resources development carried out for four fiscal years from 1975 to 1978 in cooperation with the both governments of Japan and Estados Unidos Mexicanos.

The details of the survey have been reported in each of the annual reports submitted every year. Therefore the composite summary of the annual reports and the outlines of various surveys are to be described here.

I.1 Purpose of Survey

The primary purpose of this project was to obtain the basic data for exploration and development of mineral resources in the target area of 16,000 square kilometers in the Coahuila State, northern Mexico by conducting surveys such as aeromagnetic survey, LANDSAT data analysis, photogeological interpretation, surface geological survey, geochemical prospecting, geophysical prospecting, and exploratory diamond drilling. Practically, the surveys were directed to the investigation of various metallic mineral deposits and fluorite deposits which are closely associated with intrusive igneous rocks in the Cretaceous carbonate rocks distributed throughout the project district.

I.2 Outline of Surveys

Areas, methods, and quantities of the surveys carried out each year were listed in Tables 1 and 2. Locations of the survey areas are shown in Fig. 2.

The surveys in Phase I consists of aeromagnetic survey throughout the whole district (16,000 km^2), collection of geological data of the district to be surveyed, and inspection of operating mines in and around the district.

As the result of aeromagnetic survey, total magnetic intensity map, residual map, map of second vertical derivative and pseudo gravity map were made, which led to the assumption of the presence of magnetic bodies,

Fig. 3 PROGRESS OF SURVEY WORK

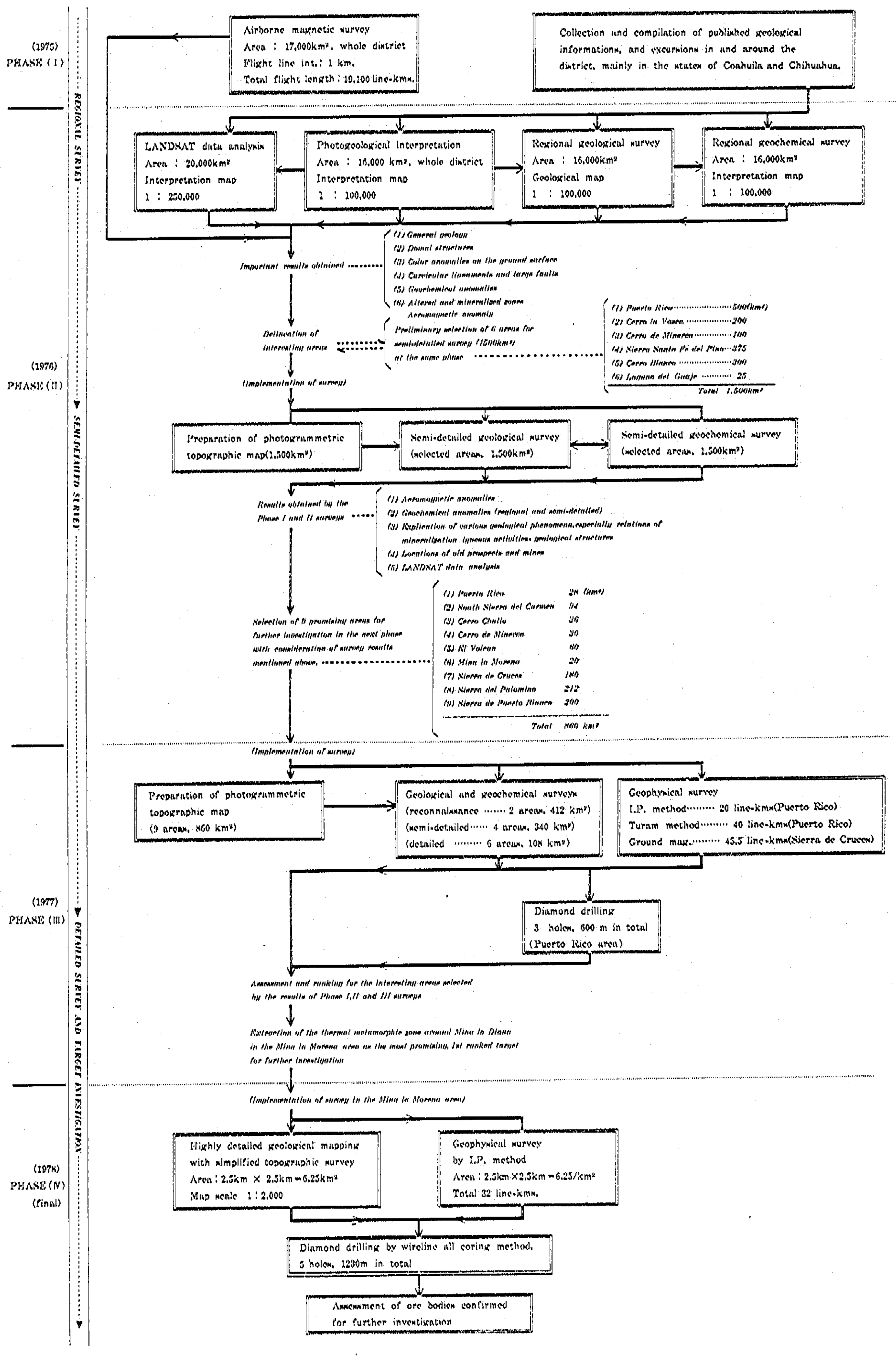


Table 1 Method and Type of Survey Work

Type of survey	Method of survey	Covered area in total (km^2)	Scale of interpretation map
Geological survey	Photogeology	16,000	1:100,000
	Regional geological survey	16,412	1:100,000
	Semi-detailed geological survey	1,840	1:50,000 to 25,000
	Detailed geological survey	115	1:10,000 to 2,000
Geochemical survey	Regional survey (stream sediments)	16,412	1:100,000
	Semi-detailed survey (soil and stream sediments)	1,840	1:50,000 to 25,000
	Detailed survey (soil and rock)	108	1:10,000 to 5,000
LANDSAT data analysis	Geologic interpretation by pseudo-natural color composite image	16,000	1:250,000
	Lineaments analysis by edge-enhanced image	16,000	1:250,000
	Digital classification map of geologic units by digital analysis of CCT	16,000	1:250,000
	Discrimination of mineralized zone by digital analysis of CCT	16,000	1:250,000
Geophysical survey	Airborne magnetic survey	17,000	1:100,000
	Electric survey by IP method	7.1	1:5,000
	Electromagnetic survey by TURAM method	3.8	1:5,000
	Ground magnetic survey	37	1:5,000
Diamond drilling	Wireline all core boring	3 holes, 600m in Puerto Rico	drill core log
		5 holes, 1,240 in Mina la Moreia	1:200
Miscellaneous	Preparation of photogrammetric topographic map	2,360	
	Investigation for private mining concessions	860	

Table 2 Laboratory Examinations

Type of examination	Number of samples	Number of elements
Chemical analysis of geochemical sample (stream sediments)	2,761	
Chemical analysis of geochemical sample (soil)	1,489	28,220
Chemical analysis of geochemical sample (rock)	2,040	
Chemical analysis of ore sample	484	2,689
Whole rock chemical analysis	8	105
Microscopy of rock thin section	455	
Microscopy of ore polished section	46	
K-Ar age determination	24	
Fossil identification	198	
X-Ray powder diffractmetry	26	
E P M A - analysis	47	
Fluid inclusion test	10	
Measurement of rock magnetism	10	
" of magnetic susceptibility	54	
" of resistivity	48	
" of frequency effect	25	

especially of the blind bodies of intrusive rocks.

The surveys in Phase II consist of regional reconnaissance throughout the whole area including LANDSAT data analysis, photogeological interpretation, regional geological survey and regional geochemical survey, and semi-detailed survey of geology and geochemistry for six areas (500 km^2 in total) selected by means of examining the previous data and the photogeological interpretation.

The six areas selected are as follows:

(1)	Puerto Rico area	500 (km^2)
(2)	Cerro la Vasca area	200
(3)	Cerro de Minerva area	100
(4)	Sierra Santa Fé del Pino area	375
(5)	Cerro Blanco area	300
(6)	Laguna del Guaje area	25

Among these, the Laguna del Guaje area was surveyed for the potentiality of evaporite deposits in the adjoining area of a lagoon located in the central plain of the district, and the subject of investigation was naturally different from other five areas.

For the next step, nine areas (860 km^2 in total) were selected, taking the results of regional surveys such as

(1) Aeromagnetic anomalies
(2) Dome-shaped circular structures obtained from LANDSAT data analysis
(3) Geochemical anomalies
(4) Geological structures, mineralized zones, distribution of intrusive rocks

and a part of semi-detailed surveys into account.

The surveys in Phase III were conducted for the nine areas selected as follows:

(1) Puerto Rico area, 28 km^2
Detailed geological and geochemical survey, detailed survey of outcrops in mineralized zones, electric prospecting by IP method,

electromagnetic prespecting by TURAM method, and pilot drilling (200 m x 3 holes).

(2) South Sierra del Carmen area, 94 km^2
Semi-detailed geological and geochemical survey, and detailed survey of mineralized zones.

(3) Cerro Chalio area, 36 km^2
Semi-detailed geological and geochemical survey.

(4) Cerro de Minerva area, 30 km^2
Detailed geological and geochemical survey.

(5) El Volcan area, 60 km^2
Semi-detailed geological and geochemical survey, and detailed survey of mineralized zones.

(6) Mina la Morena area, 20 km^2
Detailed geological and geochemical survey.

(7) Sierra de Cruces area, 180 km^2
Semi-detailed geological and geochemical survey, detailed survey of mineralized zones and ground magnetic survey.

(8) Sierra del Palomino area 200 km^2

(9) Sierra de Puerto Blanco area, 212 km^2

The last two areas were located outside the initial project district. These two areas were found as the result of LADSAT data analysis made in the wide region including the project district and its surroundings, in which dome-shaped circular structures were recognized, and recommendations were made also from the geological standpoint to be important targets for prospecting. Accordingly, geological and geochemical reconnaissances were carried out.

By compiling all these surveys, examinations were made on the age and characteristics of igneous activity, its relation with mineralization, localities of ore deposits, ore bearing horizons, etc. Consequently, as the result of relative evaluation of favorable mineralized zones and altered zones, a recrystallized zone of limestone in the Mina la Morena area was finally selected with first priority, and recommended as a target for the next exploration.

In Phase IV, the last phase of the project, detailed surveys were conducted in the area of 2.5 km x 2.5 km in accordance with the recommendation of Phase III, at the center of which the recrystallized zone of limestone in Mina la Morena area is located.

(1) Detailed Geological Survey

The survey lines were set to cover the whole area of survey spaced 50 meters apart from each other. Geological mapping was done with the scale of 1 : 1,000 describing all rock exposures, and mineralized outcrops were sketched and sampled. The result of survey was compiled to geological map of 1 : 2,000 scale.

(2) Geophysical Survey

Electric survey of IP method was carried out along the survey lines spacing 100 meters apart, with coefficient of electrode separation of n = 4. The results of various analyses were compiled to the maps of 1 : 5,000 scale.

(3) Diamond Drilling

Five drill stations were selected by the results of examination of detailed geological survey and IP survey. Five holes were drilled to the depth from 203 m to maximal 300 m with the total length of 1,240.90 m.

As the results, ore showings of silver, copper, zinc and lead, the shapes of vein, manto, and partly pod of probably high temperature hydrothermal origin were confirmed in the limestone of the Aurora formation.

All the course of surveys conducted in these four phases are compiled as follows:

Phase I and Phase II	Regional survey of the whole survey district (16,000 km²) and semi-detailed survey of a portion.	Aeromagnetic survey, LANDSAT data analysis, Photogeology, Regional geological and geochemical surveys, Semi-detailed geological and geochemical surveys in the six areas.
Phase III	Semi-detailed and detailed surveys, and evaluation of mineralized and alteration zone of the selected areas (860 km²)	Regional to detailed geological and geochemical surveys of the nine areas, Geophysical (IP and EM) survey and drilling in one area, Magnetic survey in one area.
Phase IV	Prospecting of mineralized zones in the most promising area (6.25 km²)	Detailed geological mapping, geophysical (IP) survey, and drilling in mineralized zones.

I.3 Previous Investigation

The whole or a part of the project district is covered by the geological maps shown as follows:

i) Geologic map of northern Coahuila, Mexico (1 : 250,000) by C.I. Smith (1970)

ii) Plano Geologico Estado de Coahuila y Norte de Nuevo Leon (1 : 500,000) by CRM (1976)

iii) Geological Maps (1 : 50,000) of "Cenzontle", "Norias del Caballo", "Palo Blanco" and "El Carmen" by Comisón de Estudios del Territorio Nacional (CETENAL)

The other available data and literatures are listed as references at the end of this report.

I.4 Members

Members participated in the project are listed in Table 3.

I.5 Acknowledgements

The project which was initiated in 1975 had been conducted for four years and completed the whole program by the end of fiscal 1978. We have greatly appreciated the cooperation, guidance and encouragement of appropriate governmental organizations and persons concerned both in Mexico and Japan. We are especially grateful, in Mexico, to Dr. H. Takeda of Geological Survey of Japan (staying in Mexico as a member of Consejo de Recursos Minerales despatched by Japan International Cooperation Agency as specialist), Mr. M. Iida, Manager of Mexico Office of Dowa Mining Company. Messrs. H. Kamono and Y. Harada of EMIJAMEX Company Ltd., and Ing. E. Rerma, resident manager of Hércules mine of Minera Norte S.A., and in Japan, to Drs. H. Matsuno, K. Tanaka and K. Hoshino of Geological Survey of Japan for their useful advice and

guidance.

The survey team submits herewith the final report on the geological survey which we have been carrying on in the United Mexican States since 1975.

On this occasion, all members of the survey team pray for the bliss of the late Mr. T. MIYOSHI who unfortunately passed away in Mexico during the survey.

We would like to express our sincere gratitude again for the great support extended to us by Mr. Ing. Guillermo P. Salas, Director General del Consejo de Recursos Minerales de Mexico and all of his staffs, Japanese Embassy at Mexico, Japan International Cooperation Agency, Metal Mining Agency of Japan and all the people concerned in Mexico.

Table 3 Members List

Note : CRM .... Consejo de Recursos Minerales
MITI .... Ministry of International Trade and Industry
JICA .... Japan International Cooperation Agency
MMAJ .... Metal Mining Agency of Japan

		Planning and Management		Field Survey Team		
		Name	Belonging to	In Charge of	Name	Belonging to
1975	Japan	Hiroshi Saruhashi	MITI	Chief, General	Hideo Otsu	MMAJ
		Tsuyoshi Konno	JICA	Geology	Motomu Kiyokawa	"
		Akira Sato	MMAJ	Geophysics	Mitsuya Takahashi	"
		Shinsei Terashima	"			
		Kunio Asakura	MMAJ, resident in Mexico			
	Mexico			Geology	Panfilo Sanchez Alvarado	CRM
				Geophisics	Cesar J. Villegas	"
				"	Juan H. Mendoza	"
		Guillermo P. Salas	CRM	"	Jose L. Rangel Cruz	"
		José L. Lee Moreno	"	Aviation	Enrique Garcia Léon	"
		Mauricio de la Fuente	"	"	Fransisco Perez Alvarez	"
		de D.		"	David de la Luz Valdes	"
				"	Marcial Benitez Plata	"
1976	Japan			Chief, General	Tadao Hamajichi	MMAJ
				Geology	Motomu Kiyokawa	"
				"	Tamotsu Nakajima	"
		Akira Sato	MMAJ	"	Hiroshi Miyajima	"
		Tsuyoshi Ogitsu	"	"	Takeomi Miyoshi	"
		Kunio Asakura	MMAJ, resident in Mexico	"	Fumio Wada	"
				"	Haruo Watanabe	"
				"	Akio Abe	"
	Mexico			Geology	Panfilo Sanchez Alvarado	CRM
				Photogeology	Miguel Priego de Wit	"
				Geology	Emilio Flores Espinoza	"
		Guillermo P. Salas	CRM	"	Fransisco J. Garcia Genis	"
		José L. Lee Moreno	"	"	Rafael Valladolido Cacho	"
		Mauricio de la Fuente	"	"	Miguel Angel Miranda Gasca	"
		de D.	"	"	Victor Lopéz Bedolla	"
		Guillermo Monroy Ochoa		"	Hector Perez Martinéz	"
				Assay	Antonio Ortiz Castillo	"

Table 3 Members List (continued)

Year	Country	Planning and Management: Name	Planning and Management: Belonging to	Field Survey Team: In Charge of	Field Survey Team: Name	Field Survey Team: Belonging to
1977	Japan			Chief, General	Motomu Kiyokawa	MMAJ
				Geology	Tamotsu Nakajima	"
				"	Hiroshi Miyajima	"
		Ken Fujita	JICA	"	Takeomi Miyoshi	"
		Akira Sato	MMAJ	"	Haruo Watanabe	"
		Tsunehiko Kotaki	"	"	Tetsuo Sato	"
		Yukio Harada	MMAJ, resident in Mexico	Geophysics	Mitsuya Takahashi	"
		Motomu Kiyokawa	MMAJ	"	Katsumi Sera	"
				Drilling	Shohei Abe	"
				"	Shunro Matsumoto	"
	Mexico			Geology	Panfilo Sanchez Alvarado	CRM
				"	Fransisco J. Garcia Genis	"
				"	Rafael Valladorid Cacho	"
				"	Hector Perez Martinez	"
				"	Miguel A. Olera Cano	"
				"	Juan M. Lopez Medel	"
		Guillermo P. Salas	CRM	"	Gerardo Gonzalez Faustino	"
		José L. Lee Moreno	"	Geophysics	José F. Hernandez Martinez	"
		Mauricio de la Fuente de D.	"	"	Hemiro Alvarez Machiel	"
		Gustavo Camacho Ortega	"	"	Marco A. Cifuentez Diaz de Leon	"
				"	Juan F. Hernandez Garcia	"
				"	Soccoro Garcia Pineda	"
				"	Jesus Garcia Pineda	"
				Drilling	Marcelino Perez Herandez	"
				"	Javier R. Dororiguez Torres	"
				"	Efrain Gonzalez Serratoo	"
				"	Almando Escokedo Hernandez	"
1978	Japan	Mitsuru Suemori	JICA	Chief, General	Motomu Kiyokawa	MMAJ
		Tsuyoshi Konno	MMAJ	Geology	Hiroshi Miyajima	"
		Kenji Sawada	"	"	Akio Abe	"
		Yukio Harada	MMAJ, resident in Mexico	"	Tetsuo Sato	"
		Motomo Kiyokawa	MMAJ	Geophysics	Takao Ogawa	"
				Drilling	Hisao Ataku	"
				"	Suekichi Kikuchi	"
	Mexico			Geology	Panfilo Sanchez Alvarado	CRM
				"	Hector Perez Martinez	"
				"	Miguel A. Olera Cano	"
		Guillermo P. Salas	CRM	"	Gerardo Gonzalez Faustino	"
		José L. Leo Moreno	"	Geophysics	Gilberto Paredes R.	"
		Mauricio de la Fuente de D.	"	"	Mario Alvear Vigueras	"
		Gustavo Camacho Ortega	"	"	Jesus Garcia Pineda	"
				Drilling	Javier R. Rodoriguez Torrez	"
				"	Eligio Arellano Vasquos	"

PART II CIRCUMSTANCES OF THE SURVEY DISTRICT

II.1 Location (Fig. 1)

The project district is located in the northwestern part of the State of Coahuila of northern Mexico, and confined to the north by the Rio Grande River flowing eastward along the American border and to the west by the border with Chihuahua. The area is rectangular in shape extending to NE-SW with E-W width of about 80 km and N-S length of about 200 km, and included in the ranges of Lat. 27°30'∿29°30' N and Long. 102° ~ 104°W extending over the counties of Melchor Ocampo and Ciudad la Acuña.

II.2 Access

Sabinas City of Coahuila is the most convenient and the nearest place to approach the project district. There are the following routes, by air and overland, from Mexico City to Sabinas City.

(1) Air route via Monterrey City, N. Leon

Mexico City ------- Monterrey City
700 km in a straight line, about an hour by jet, daily flight

Monterrey City ---- Sabinas City
304 km by land, about 4 hours 30 minutes via Routes 53 and 57 (all-weather, paved).

(2) Overland route via Saltillo City

Mexico City ------- Saltillo City ------- Sabinas City
1,175 km via Route 57 (all-weather, paved).

The following routes, northern and southern, can be taken to approach the district from Sabinas City.

Northern route :

For the northern part of the district, it takes about five hours by the northern route (257 km in distance) passing through Nueva Rosita and Muzquiz by way of Route 57, and Route 53 which is paved up to the piedmont of the Sierra del Carmen.

Southern route:

For the southern part of the district, it takes about nine hours by the southern route (350 km in distance) passing through Monclova, Cuatro Cienegas and Ocampo by way of Route 57, and Route 30 which is paved up to Ocampo.

Also air taxi by small air plane is available, as small air-strips are useful in the district near the colonies.

Since the northern route was ofen interrupted during the rainy season, and it took as long as nine hours even in good weather, the northern route was mainly used during the field operation.

II.3 Supplies

In the areas beyond Muzquiz City along the northern route and beyond Ocampo Village along the southern route, it is difficult to purchase mobil oil, fuel oil, and foods, and it is almost impossible to find out the repair shop for the car failure. Before entering the field, therefore, it is necessary to be completely equipped with all supplies such as gasoline, oil, spare tires, foods, drinking water, and other materials.

II.4 Climate and Vegetation

The climate of the district is semi-arid and belongs to high atmospheric pressure zone, with prevailing dry weather, but heavy rainfalls are encountered sometimes in wet season.

Annual rainfall is about 400 mm in desert plain and reaches 650 mm in mountainous areas of higher altitude which are 1,000 meters or higher above the desert plain.

The rainy season is brought by the easterly seasonal wind from the Gulf of Mexico which usually prevails from July to September. The rainfalls are torrential downpour type often resulting in the washout of bridges and roads.

Annual average temperature is about 18°C. However, shade temperature minimum range 0° to -10°C in winter.

Thunderstorm, hailstorm, gust wind with sand dust during summer and autumn, and snowfall from the end of November to January are also encountered.

The vegetation is varied from desert plain to mountainous highland by the change of rainfall and weather conditions due to the difference of altitude as follows:

(1) Desert plain type: This type, the most abundant in the district, is mainly distributed in the desert-like lowland and on the mountain flanks up to 1,600 m above sea level, and is characterized by sparse stocks of *Larrea mexicana, Agave lechuguilla, Forquieria splendens, Mesquite, Prosopis, Acacia and Nopal.*

(2) Transitional type: This type is distributed in the mountainous areas higher than 1,600 m above sea level, and is characterized by a mixture of grasses, woods of oak and desert vegetation including *Yucca, Noina, Agave and Desyliron.*

(3) Mountain highland type: This type, characterized by a sparse forest of pine and cedar trees, is only found in two areas of the Sierra del Carmen and Sierra Santa Fé del Pino where the elevations are higher than 2,200 m above sea level, and so it is rather cool and receives more annual precipitation.

Since the vegetation is generally thin, it is advantageous that the topographic features can be distinctly discerned in air photographs and in LANDSAT images.

II.5 Population, Colony and Indusry

The colonies in the area are confined to "Ejidos" (public settlements), mines, and private ranches. About twenty public settlements are scattered in the area, to which the land has been provided by the government. Each settlement is consist of about thirty houses with about two hundred persons who make living by public ranches, public ventures, harvesting of candelilla (wax tree), and help for private ranches. Each of public settlements has primary school, and some of them have public installations such as clinics, radio stations, airstrips, etc. Drinking water is barely ensured by pumping up the underground water, but farming can not be brought about because of the shortage of irrigation water.

The economic activity of the district depends mainly upon stock farming and mining. As for the stock farming, they mainly breed beef cattles. Some horses, asses, and goats are also raised. Most parts of the survey district make up the ranches except steep mountainous highland. There are various kinds of ranch in scale from several dozens to more than one thousand cattles and horses.

As to the mining activities in operation during the field works of the project, several fluorite mines are located in the northernmost part of the district, lead-zinc mines are located on the northwestern piedmont of the Sierra del Carmen and an iron mine is located in the northwestern part of the Sierra de Cruces. The total number of workers of these mines is about four hundreds.

II.6 Topography

The topography of the district is characterized by the mountain ranges composed mainly of Cretaceous sedimentary rocks extending in NNW-SSE direction (from north, Northern Sierra del Carmen, Sierra de San Vicente, Sierra de Harina, Sierra Santa Fé del Pino, etc.), plateau-like mountain blocks composed of Tertiary igneous rocks (Southern Sierra del Carmen, Sierra de Hechiceros, etc.), prominent hills in the plain which are composed of Tertiary intrusive rocks (Sierra de Cruces, Cerro la Vasca, Cerro de Minerva, etc.), and semi-desert peneplain underlain by Quaternary sediments, all reflecting main features of geological structures. The mountain ranges composed of Cretaceous sedimentary rocks often have anticlinorium structure and show cuesta topography. The altitude of the mountain ranges reaches from 1,400 m to 2,500 m, while plains are 800 ~ 1,100 m above sea level.

II.7 Drainage System

The Rio Grande River is the largest river in the district which has abundant water throughout the year. Besides it, there are other small rivers of perennial stream including small stream flowing to the west of Ejido la Rosita and some small creeks in the high mountainous regions.

There are to principal intermittent drainage systems. One is a system which originates from the Laguna del Guaje (meaning gourd-shaped lagoon)in the south of the project district and flows northward to the Rio Grande River through the central part of the district. Another system flows northward through the plain on the west of the Sierra del Carmen and pours to the Rio Grande River. Many swamps and lagoons are found along these drainage systems because of the small inclination of about 0.3 percent gradient.

PART III GEOLOGY

III.1 General Remarks

The pre-Cretaceous, Cretaceous, Tertiary and Quaternary systems are widely distributed within the district in ascending order.

The underlying pre-Cretaceous system is the basement of the survey district, and crops out in restricted areas in the east of the Las Norias fault located on the foot of the western escarpment of the Sierra del Carmen.

The Cretaceous system, which has the most wide distribution and forms uplift-mountain ranges, is divided into the Coahuila, Comanche and Gulf series. The Coahuila series is subdivided into the Puerto Rico and Cupido formations. The Comanche series is also subdivided into the La Peña, Glen Rose, Telephone Canyon, Del Carmen, Sue Peaks, Santa Elena, Del Rio and Buda formations, but in the southern district, the Aurora formation is distributed as a contemporaneous heterotopic facies of the Glen Rose formation, Telephone Canyon formation and Del Carmen formation. The Gulf series is composed of the Boquillas, San Vicente, Pen and Aguja formations. These strata are layered in the ascending order as described above.

The Tertiary system is mostly composed of volcanic rocks, and is delineated to three volcanic areas of the south Sierra del Carmen, the Sierra de Hechiceros and the Sierra de San José.

Those strata are penetrated by Tertiary instrusive rocks which vary widely in form, in lithology and in age.

The formation names of the Cretaceous system used in this report, which are mainly based on Maxwell et al. (1967) and Smith (1970), are listed in Table III-1 together with the characteristic fossils collected and identified in the present survey.

III.2 Stratigraphy

III.2.1 Pre-Cretaceous System

Distribution The pre-Cretaceous system is restrictedly distributed in the east of the Las Norias fault, on the foot of the western escarpment of the Sierra del Carmen, and in the north of Mina Puerto Rico.

Lithology The pre-Cretaceous system is composed of foliated, black-colored, medium-grained crystalline schist derived probably from pelitic rocks, which microscopically consists of quartz, sericite, sillimanite, biotite, tourmaline and opaque minerals.

Correlation The schist which is clino-unconformably covered by the Cretaceous system was considered to be pre-Cambrian basement adjacent to the Permian goesyncline of the south Coahuila closely linked with the Permian Texas geosyncline by Kellum et al. (1936). Smith (1970), however, regarded it as Paleozoic rock referring to the results of the absolute age determination (240 to 370 X 10^6 year) by Flawn (1958).

III.2.2 Cretaceous System

A) Coahuila Series

A)-1 Puerto Rico Formation

Name New name.

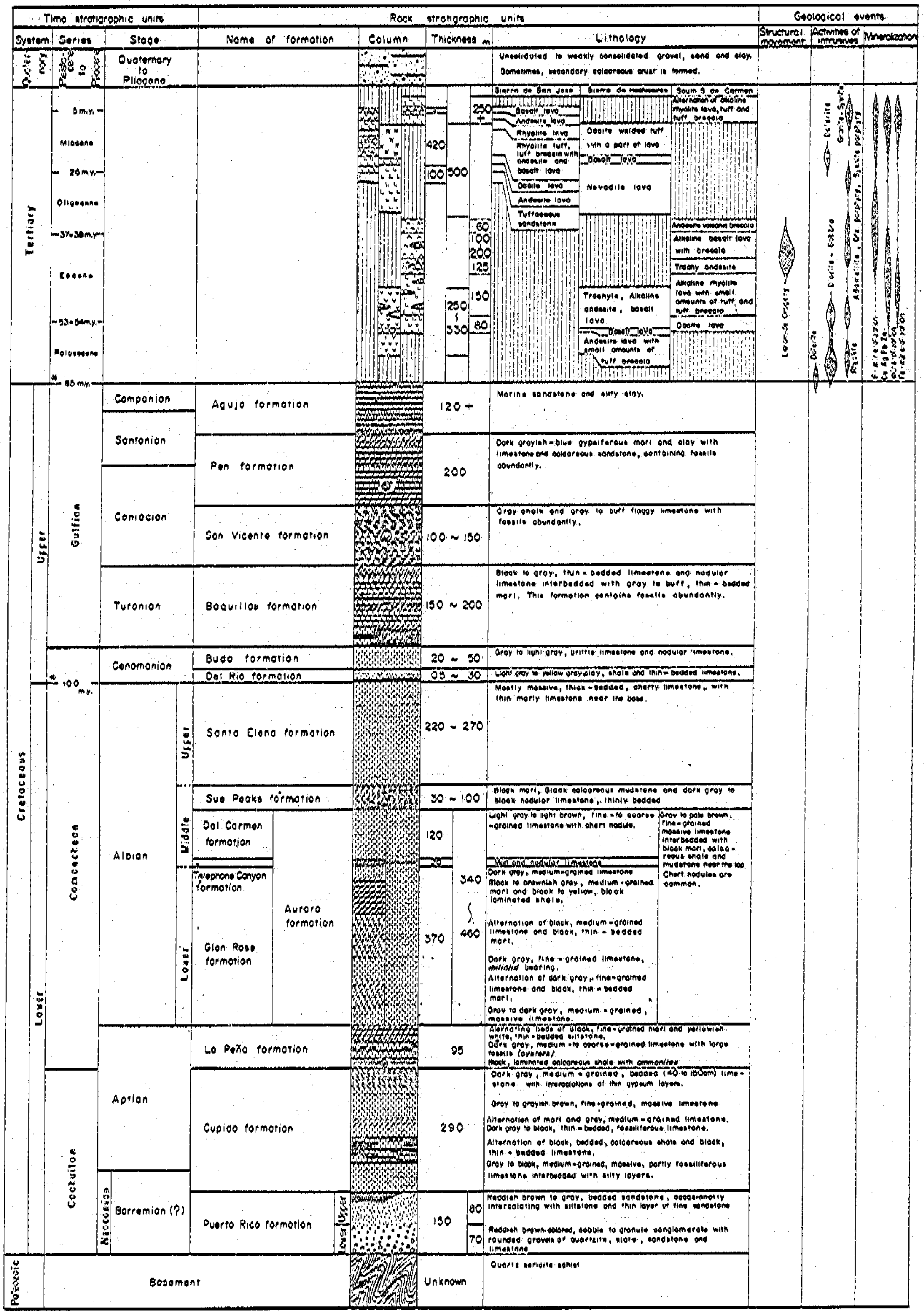
Type locality About 2 km north of Mina Puerto Rico located on the foot of the western escarpment of the Sierra del Carmen.

Thickness About 150 m.

Distribution This formation is distributed to the north from the type locality along the eastern side of the Las Norias fault intermittently.

Lithology The Puerto Rico formation comprises the lower and upper members.

Fig. III-1 GENERALIZED STRATIGRAPHIC COLUMN OF THE DISTRICT



※ Referred from The introduction of geochronology, "when the earth was born", Kojima M., 1973, TOKYO Univ. Press.

Table Ⅲ－1 Cretaceous Molluscan Fossils of the District

Age		Formation		Characteristic fossils
Campanian	Early	Pen	upper	Delawarella danei *Placenticeras meeki*
Santanian	Late ~ Middle		lower	*Inoceramus (Platyceramus)* cf. *platinus*
	Middle ~ Early	San Vicente	upper	*Inoceramus (Cladoceramus) undlatoplicatus* *Texanites (Texanites)* cf. *Texanus*
	Early			*Inoceramus (Platyceramus)* ex gr. *cycloides*
Coniacian	Late ~ Middle		middle	*Inoceramus* cf. subquadrates *Inoceramus* cf. *stantoni*
	Early		lower	*Didymotis* sp.
Turonian	Late	Boquillas	upper	*Inoceramus* aff. *perplexus* *Inoceramus (Mytiloides)* aff. *latus*
	Middle		middle	*Inoceramus (Inoceramus)* ex gr. *lamarrki*
	Early		lower	*Inoceramus (Mytiloides)* labiatus
Cenomanian	Middle Early	Buda		*Inoceramus* aff. *crippsi*
	Early	Del Rio		*Budaiceras sp.*
Albian	Late	Santa Elena		
	Middle	Sue Peaks	upper	*Oxytropidoceros (Adkinsites)* bravoensis *Venezoliceras* aff. *texanum*
			middle	*Hoplites* sp.
			lower	*Cleoniceras sp.*
	? Early	Aurora	upper	*Douvilleiceras* sp.
				Hypacanthoplites sp. *Acanthohoplites* sp.
Aptian	Late	La Peña		*Australiceras* sp.

(This list is prepared by the leading fossils collected by the regional and semi-detailed survey.)

The lower member, about 70 m thick, is mainly composed of characteristic reddish brown-colored conglomerate.

The upper member, about 80 m thick, is mainly composed of reddish brown-colored arkose sandstone with the stratification of 10 to 50 cm interval and interbedded with thin granule conglomerate and shale.

Environment   This formation shows characteristic reddish brown color suggesting its terrestrial origin, but the upper member is inferred to be transitional facies to the marine environment because of being well-sorted, shale intercalations, calcareous cementing material of arkose sandstone throughout the upper part.

Correlation   The lower part was reported to represent probably the deposition of the lowermost of Cretaceous or older by Smith (1970), while the upper part was considered to correspond to the La Mula formation by Humphrey (1956).

In this report, the Puerto Rico formation is treated as the basal part of the Cretaceous system where the lower part is the basal conglomerate of the Cretaceous. It is due to the fact that the lower part contains fresh limestone pebble, graduatedly changing to the upper part showing a series of graded bedding throughout the entire formation.

The Puerto Rico formation is correlated to the La Mula formation named by Imlay (1940).

A)-2 Cupido Formation

Name   It was named by Imlay (1937), and redefined by Humphrey (1949).

Type locality   The central part of the Sierra de Parras, situated about 60 km southeast of Parras, Coahuila, is the type locality of the Cupido formation. In the survey district, the formation is typically cropped out at the lower part of the western escarpment of the Sierra del Carmen, west of Pico Puerto Rico, as a narrow belt of 6 km long.

Distribution The type locality, the central part of the Sierra Santa Fé del Pino and the northern end of the Sierra de Corazon are the main localities of the Cupido formation.

Thickness The Cupido formation is about 290 m thick in the west of Pico Puerto Rico, about 200 m + thick in the Sierra Santa Fé del Pino and about 150 m thick at the northern end of the Sierra de Corazon.

Lithology In the west of Pico Puerto Rico, the Cupido formation is composed of the upper and lower parts which are dominant in limestone, and the middle one which is the alternation of muddy and calcareous beds.

Environment The Cupido formation in the Sierra del Carmen is comparatively rich in terrigenous clastics, and contains many fossils such as miliolids, pelecypods, gastropods, stromatolite, etc., suggesting the deposits under the very shallow littoral environment. The depression is inferred to have progressed intermittently and gradually, accompanying a slight and occasional uplift judging from variation of the contents of the terrigenous clastics. The Cupido formation in the Sierra Santa Fé del Pino and in the northern end of the Sierra de Corazon is relatively uniform in constituents and lacks in large fossils to suggest the deposits under deeper marine environment than in the Sierra del Carmen area.

Correlation The Cupido formation occupies the uppermost of the Coahuila series, and is correlated to the Early to Middle Aptian age.

B) Comanche Series

B)-1 La Peña Formation

Name It was initially named by Imlay (1936) in the Sierra de Parras, south Coahuila, and redefined by Humphrey (1949).

Type locality The La Peña formation was at first reported from Rancho la Peña located on the northern piedmont of the Sierra de la Encantada, north Coahuila. In the survey district, it is typically exposed at the lower middle part of the western escarpment of the Sierra del Carmen located in the west of Pico Puerto Rico.

Distribution The La Peña formation is distributed overlying the Cupido formation in the Sierra Santa Fé del Pino and in the north of the Sierra de Corazon together with the type locality.

Thickness In the Sierra del Carmen, the La Peña formation consists of three lithological units of the lower, the middle and the upper, and has about 95 m thickness in total. In the Sierra Santa Fé del Pino, the lower limit is lost by fault and has about 90 m + thickness. At the northern end of the Sierra de Corazon, about 348 m thickness is reported (Hernández, 1964).

Lithology In the Sierra del Carmen area, the La Peña formation is divided into the lower composed of thin-bedded black-colored calcareous shale (about 33 m thick), the middle of thickly stratified dark gray-colored medium- to coarse- grained limestone interbedded with thin nodular limestone (about 36 m thick), and the upper composed of the alternation of black-colored moderately stratified marl and yellowish gray calcareous siltstone (about 26 m thick).

In the Sierra Santa Fé del Pino, the formation is mainly composed of medium- to thin-bedded (10 ∿ 30 cm) black calcareous mudstone. Macrofossils are not recognized.

At the northern end of the Sierra de Corazon, it consists of thinly bedded dark-colored limestone and black shale.

Environment The La Peña formation is widely distributed in the northern Coahuila, bounds on the Cupido formation sharply but gradationaly, and is presumed to have been deposited under the opende sub-littoral environment where water was aggitated by wave and wind, judging from the characteristic lithofacies and an abundance of shallow benthonic fossils such as gastropods, cephalopods, etc. On the abrupt change of the lithofacies from the Cupido formation, background stretching caused by an epeirogenic uplift and/or marine regression is inferred to occur in the northern area (Smith, 1970).

Correlation   As *Dufrenoya* accompanied with *Paraholites* was found from this formation, this formation was correlated to Late Aptian stage by Smith (1970). Also *Australiceras* which shows Late Aptian age makes it sure.

B)-2 Glen Rose Formation

Name   The name of Glen Rose was introduced by Hill (1891) to outcrops along the Paluxy River near to Glen Rose in Somervell Country of Texas, and was initially reported in the northern Coahuila by Dumble (1895).

Type locality   The Cerro el Palmo in the Sierra del Burro located east outside of the survey district is regarded as the type locality of this formation in the northern Coahuila, and is typically exposed on the middle part of the western escarpment of the Sierra del Carmen to the west of Pico Puerto Rico.

Distribution   The Glen Rose formation is restrictedly distributed in the Sierra del Carmen in the survey district. It crops out on the western escarpment of the Sierra del Carmen as a narrow belt and in the western big branches of the Arroyo del Veinte on the Sierra del Carmen as windows.

Thickness   About 370 m thick in the west of Pico Puerto Rico.

Lighology   Lithologycally this formation is subdivided into 1st to 6th units in ascending order.

Environment   The Glen Rose formation is inferred to have deposited under a very shallow littoral environment represented by miliolids and *Orbitolina* in the basin, where the bottom was broad, almost flat and slightly inclined to the south. Also the basin was some 100 to 160 km wide, extending to the east across northern Coahuila and south Texas, thence to the northeast passing Central Texas. The characteristic stairstep topography of the Glen Rose formation is assumed to have been resulted by the alternation of less resistant marly layers and more resistant limestone beds which were presumably brought by periodical change of the supply of fine-grained terrigenous clastic material in concordance with periodic epi-orogenic movement.

To the south of the Sierra del Carmen, the Aurora formation which is of deeper marine facies, and is characterized by poor terrigenous clastics and rather uniform lithofacies, deposited as a contemporaneous heterotopic facies of the Glen Rose formation.

Correlation The ammonites collected from the lower part of the Glen Rose formation (presence of *Parahoplites, Hypacantoplites* and *Douvilleiceras*, and absence of *Dufrenoya*) indicate the earliest Albian age. Critical ammonite fossils have not been found in the upper Glen Rose from the district. It is, however, certain that the Glen Rose formation is Early or Middle Albian in age, since *Oxytropidoceratid* ammonites, Middle Albian zonal marker, are found in the Sue Peaks formation (Smith, 1970).

B)-3 Telephone Canyon Formation

Name The formation was named by Maxwell et al. (1967) for the thin-bedded nodular limestone and marl at the Telephone Canyon in the American Sierra del Carmen.

Type locality The type locality of the Telephone Canyon formation is the Telephone Canyon in the American Sierra del Carmen located about 12 km west of La Linda which is a border town in the north Sierra del Carmen. In the survey district, it is typically cropped out on the western escarpment of the Sierra del Carmen.

Distribution This formation has almost the same distribution as the Glen Rose formation in the Sierra del Carmen.

Thickness About 20 m thickness is obtained at the typical outcrop of the west of Pico Puerto Rico.

Lithology This formation is less resistant against weathering, consists of medium-to thin-bedded alternation of brownish gray- to dark gray-colored limestone and black marl with abundant fossils, is penetrated by iron-oxide network veinlets, and is gradationally overlain on the Glen Rose formation.

Environment The Telephone Canyon formation is regarded as terrigenous fine clastics rich in shallow littoral deposits during the marine transgression period subsequent to the Marathon area uplift which contemporaneously occurred with the regression of the Glen Rose sea, and is generally abundant in benthonic molluscs.

Correlation Although critical fossils are not found from this formation to determine the exact age, the collected fossils comprise a typical Middle Albian fauna, and are very similar to those of the Walnut formation of Texas (Smith, 1970).

B)-4 Del Carmen Formation

Name The Del Carmen formation was initially used by Maxwell et al. (1967) for the cliff-forming limestone overlying the Telephone Canyon formation in the Sierra del Carmen in Texas, U.S.A.

Type locality The Del Calmen formation which crops out in the American Sierra del Calmen continues to the Mexican Sierra del Carmen, and is typically exposed in the upper part of the western escarpment of the Sierra del Carmen.

Distribution The formation is restrictedly distributed in this Sierra del Carmen area, and is recognized in the western escarpment of the Sierra del Carmen, the east of Boquillas del Carmen, the central part of the Agua Chile dome and Mina la Cueva dome, and the western branch of the Arroyo del Veinte as windows.

Thickness The formation is about 122 m thick in the west of Pico Puerto Rico, and about 81 m thickness is reported from the Cerro Agua Chile (Smith, 1970).

Lithology The Del Carmen formation is composed of the lower, middle and upper parts, and gradationally overlies the Telephone Canyon formation.

Environment The Del Carmen formation is inferred to be deposited under sub-littoral clean-water conditions with many benthonic faunae and with poor supply of terrigeneous clastics in the period when the marine regression extended to the feeding area of fine clastic materials during the Telephone Canyon age.

Correlation Although no critical fossil is found from this formation, it is believed that the Del Carmen formation did not invade into the Middle Albian age for the same reason as the Glen Rose formation. This formation is correlated to the Edward formation of Texas and is considered to correspond to the West Nueces formation and Mcknight formation to the east of the district (Smith, 1970 and Maxwell et al., 1967).

B)-5 Aurora Formation

Name The name was initially introduced by Burrows (1910) in Chihuahua.

Type locality The Aurora formation is named for the typical exposure in the vicinity of the Aurora mine located in Serania del Cuchillo Parado, Chihuahua. In the survey district it is typically exposed in the Cañon Tara, about 12 km west-southwest of Ejido San Guillermo.

Distribution The Aurora formation is distributed in south of the Cerro la Vasca, forming the principal mountain ranges and blocks such as the Cerro la Vasca, the Cerro de Minerva, the Sierra Santa Fé del Pino, the Sierra la Maquina, the Sierra de Corazón, the Sierra de las Moras, the Sierra de Almagre, etc.

Thickness Thickness of the formation is about 462 m + in the Cañon Tara located in the northern part of the Sierra Santa Fé del Pino, about 305 m + in the Cerro la Vasca, and 150 m + in the west of the Serra la Maquina. About 860 m thickness is reported in the northern part of the Sierra de Corazón (Hernández, 1964).

Lithology Sierra Santa Fé del Pino --- The Aurora formation is well exposed between the Cañon Tara and the Cañon de Oso, and lithologically subdivided into 1st to 6th units in ascending order, where upper units are comparatively rich in terrigenous fine clastics.

Environment The Aurora formation is considered to be southern contemporaneous heterotopic facies of the Glen Rose formation, the Telephone Canyon formation and the Del Carmen formation which are restrictedly distributed in the northern district, and to deposit under a bathyal-to-subbathyal environment with a bottom which is gently inclined to the south. The border between the Aurora and its equivalent three facies is believed to lie near the southern end of the Sierra del Carmen, though the border is not precisely delineated, because these are not exposed in the Rio Bravo folded zone and in the desert-like lowland between the Sierra del Carmen and the Cerro la Vasca.

Correlation *Douvilleiceras* indicates that it is of Lower Albian. The lowermost part, however, of the Aurora formation in the eastern foot of the Sierra de Chile located northeast of the Sierra Santa Fé del Pino contains *Hypacanthoplites* and *Acanthohoplites*, which may suggest some possibility that the Aurora formation belongs to Late Aptian.

B)-6 Sue Peaks Formation

Name The name of Sue Peaks was initially used by Maxwell et al. (1967) for the marly formation overlying on the Del Carmen formation in the American Sierra del Carmen.

Type locality Type locality of this formation is Sue Peaks in the American Sierra del Carmen. In the present survey district, it is typically exposed on the western escarpment of the Sierra del Carmen, west of Pico Puerto Rico.

Distribution The Sue Peaks formation is widely distributed in the almost all of main mountain ranges where the Cretaceous sediments are mainly observed, such as the Sierra del Carmen, the Sierra de la Encantada, the Cerro la Vasca, the Cerro de Minerva, the Sierra Santa Fé del Pino, the Sierra la Maquina, the Sierra de las Moras, the Sierra de Corazón, the Sierra de Almagre, etc.

Thickness Thickness of the Sue Peaks formation is about 110 m in the west of Pico Puerto Rico, about 30 m in the Cerro la Vasca, about 50 m in the Cerro de Minerva and about 40 m in the Cañon Tara situated in the northern part of the Sierra Santa Fé del Pino. Also about 155 m thickness is reported in the northern part of the Sierra de Corazón (Hernández, 1964).

The wide variation of thickness of the Sue Peaks formation is partly due to the confused definition of the Sue Peak formation, that is, in the vicinity of the Sierra del Carmen area it is used as the same meaning as Maxwell et al., while in the southwestern area of the Sierra de la Encantada and the Cerro la Vasca, limestone which belongs to the upper part of the Sue Peaks formation may possibly be treated as a part of the Santa

Elena formation, because it is undistinguishable lithologically from the lower part of the Santa Elena formation.

Lithology   Sierra del Carmen --- The Sue Peaks formation in the area is subdivided into the lower and upper members. The lower part, which is about 40 m thick and poorly exposed, is mainly composed of yellowish gray shale and its alternation with fine-grained limestone and nodular limestone. The upper one, which is about 70 m thick, is mainly composed of medium- to thick-bedded, pale brown-colored, medium-to fine-grained limestone interbedded with thin grayish brown shale, and accompanied with chart nodules in the uppermost part.

Environment   The Sue Peaks formation is inferred to have deposited under a sublittoral marine environment with many benthonic faunae, and partly under a reducing condition with pyrite and abundant organic materials, curing the regressive period subsequent to the regional transgression of the Del Carmen age.

Correlation   Smith (1970) regarded the Sue Peaks formation as Middle Albian based on some critical ammonites. It is correlated to the Kiamichi formation of Texas. It can not deny, however, that the Sue Peaks formation was deposited during Early Albian to Late Albian, because *Cleoniceras* may indicates Early Albian, *Oxythopideceras (Adkinsites) bravoensis* is a disputable fossil on the age, and *Venezoliceras texanum* indicates the uppermost of Middle Albian to the lowermost of Late Albian.

B)-7 Santa Elena Formation

Name   The name of Santa Elena was initially introduced by Maxwell et al. (1967).

Type locality   The type locality of the Santa Elena formation is the Santa Elena Canyon located about 30 km northwest of the survey district. Also it is typically exposed at Pico Puerto Rico and in the Cañon Tara of the Sierra Santa Fé del Pino.

Distribution The Santa Elena formation is mainly distributed in the main moutain ranges and blocks such as the Sierra del Carmen, the Cerro la Vasca, the Cerro de Minerva, the Sierra Santa Fé del Pino, the Sierra la Morena, the Sierra de la Concordia, the Sierra la Maquila, the Sierra de la Moras, the Sierra de Corazón, the Sierra de Almagre, etc., especially in the Rio Bravo folded zone in the south of the Big Bend National Park.

Thickness Thickness of the Santa Elena formation is about 250 to 280 m at Mina Puerto Rico, about 300 m in the upper stream of the western branch of the Arroyo del Veinte, about 250 to 300 m in the Rio Bravo folded zone, about 250 m in the Cerro la Vasca, about 230 m in the Cañon Tara and about 220 m in the Sierra la Maquina. Also about 150 m thickness is reported in the Cerro Agua Chile, and about 300 m in the southwest of the Sierra de Cruces.

Lithology The Santa Elena formation has generally uniform rock facies throughout the district and contains many fragmental fossils. In the south of the Sierra Santa Fé del Pino, however, it lacks macrofossils. Generally it is very resistant against weathering to form extremely steep cliff on the back slopes, and mainly composed of light gray fine-grained limestone.

Environment The Santa Elena formation is generally very poor in terrigenous materials, and is assumed to have deposited under a neritic marine condition in the western sedimentary basin separated by the reef-limestone (Devils River formation) during local regressive period.

Correlation The Santa Elena formation is correlated with the Georgetown formation of Texas, and probably corresponds to the Late Albian age.

B)-8 Del Rio Formation

Name The name of Del Rio was initially introduced by Hill and Vaughan (1898) at Del Rio, Val Verde County, Texas.

Thereafter, Adkins (1933) correlated it to the Grayson Marl formation of the central Texas and abandoned the name of Del Rio. However, it was reviewed by Maxwell et al. (1967), since the lithofacies in the Big Bend National Park area was much more similar to the Del Rio than to the Grayson Marl.

Type locality As mentioned above, the Del Rio formation is named for the claystone-dominant formation of Del Rio, Val Verde County, Texas, and typically exposed in the downstream of the Cañon de San Juan which flows down from the Sierra del Carmen, and in the upper stream of the Cañon Tara in the Sierra Santa Fé del Pino.

Distribution The Del Rio formation has almost the same distribution as the Santa Elena formation and mainly crops out as a narrow belt on the foot of the mountain ranges and blocks.

Thickness Thickness of the Del Rio formation is 1.5 m in the Cañon de San Juan, 0.5 to 0.6 m in the Rio Bravo folded zone, about 15 m in the Sierra Santa Fé del Pino, and about 10 m in the Sierra la Maquina. Generally, it tends to be thinner in the northern part of the district.

Lithology In the Cañon de San Juan to the west of the Carmen dome, the Del Rio formation is composed of the lower and upper parts which are of dark gray claystone weathered to brownish gray and about 0.3 m thick, and the middle part about 90 cm thick of dark gray thin-bedded marl. A small amount of sandstone is also recognized in the southwest of the canyon.

Environment The Del Rio formation is characterized by predominant terrigenous fine clastics, which were probably derived from the grand background raised at the end of the Santa Elena age and subsequently depressed in the district. In the sedimentary process, an open-littoral and reducing condition with abundant organic matters is assumed.

Correlation As mentioned above, the Del Rio formation is correlated with the Del Rio formation in the Val Verde County and the Grayson Marl in the central Texas. The age of it is probably Early Cenomanian.

B)-9 Buda Formation

Name The Buda formation was initially introduced by Vaughan (1900) for the overlying limestone on the Del Rio formation.

Type locality It was named for the limestone exposed at Buda in Hays County of Texas Within the district, the Buda formation crops out typically in the Cañon de San Juan and at about 4 km northeast of Ejido Piedritas.

Distribution This formation shows a very similar distribution to the Del Rio formation. In the northern half of the area, the formation is well reserved against erosion compared with the southern half.

Thickness As the thickness of the Buda formation, about 10 to 30 m in the Sierra del Carmen, about 15 m in about 5 km northeast of Ejido Piedritas, and about 20 m in the upper stream of the Canon Tara and in the Sierra la Maquina are recognized. Also about 20 to 30 m thickness was reported from the Sierra del Alazán.

Lithology According to Smith (1970), the Buda formation in the northeastern part of the district is composed of the lower part.

Environment The Buda formation covers the Del Rio formation unconformably with sharp boundary and is inferred to have deposited under a neritic to sublittoral environment during the regression period. The absence of the Upper Cenomanian fossils between the Buda and Boquillas formations suggests that the area was risen to yield an undepositional condition during the Late Cenomanian age.

Correlation *Budaiceras* and *Inoceramus* aff. *Crippsi* which were collected from the Buda formation indicate the Early to Middle Cenomanian age.

C) Gulf Series

C)-1 Boquillas Formation

Name The name of Boquillas formation was introduced by Udden (1970) at Boquillas in Texas. After that, it was redefined and divided into the Ernst and San Vicente members by Maxwell et al. (1967). In this report, however, those are treated as the Boquillas formation and the San Vicente formation, respectively, in the same manner of Rivera (1973) and Smith (1970).

Type locality The Boquillas formation is typically exposed at Ernst Tinaja situated about 10 km northwast of Boquillas del Carmen, the border town, and in the survey district it is well exposed along the trail from La Union to Ejido Jabonsillo.

Distribution The Boquillas formation is mostly distributed in the north of the Sierra la Maquina, and is mainly observed in the synclinal intermontane lowlands and pediments of the Cretaceous moutain ranges and blocks, such as the Sierra la Maquina, the Sierra de Concordia, the Sierra de Monterrey, the Sierra la Morena, the Cerro Blanco, the Sierra Santa Fé del Pino, the Sierra del Carmen, the Sierra de los Altares, mountain rainges in the Rio Bravo folded zone, etc.

Thickness The Boquillas formation is, as mentioned above, occasionally distributed in synclinal intermontane lowlands and in comparatively flat pediments, moreover, frequently cut by many small faults to show complicated repetition. It is therefore, very difficult to obtain the true thickness precisely. Approximate thickness is measured in the following localities: about 80 m in the southern part of the Carmen dome, about 100 m in the hilly mountain area situated in the east of La Union, about 90 m at the southern end of the Sierra de San Vicente, about

150 m in the northwestern part of the Cerro la Vasca, about 150 m at the nothern end of the Sierra Santa Fé del Pino and about 100 m in the Sierra la Maquina. At the type locality, about 135 m was reported.

Lithology The Boquillas formation shows comparatively uniform rock facies and consists of thin-bedded alternation of argillaceous limestone and marl interbedded with mudstone, shale, etc., accompanying fine-grained sandstone at the bottom part. Rather resistant parts rich in siliceous limestone and compact argillaceous limestone are recognized at the top and the middle parts, which form the characteristic cuesta topography. Also black limestone with petroleum odor is locally observed.

Environment The Boquillas formation is generally rich in terrigeneous fine clastic materials, and is assumed to have deposited in the opened neritic sea. Some parts are rich in organic materials having some petroleum odor. The formation covers the Buda formation unconformably as mentioned above.

Correlation *Inoceramus perplexus* and *Inoceramus (Mytiloides) latus* which indicate Middle to Late Turonian age are found from this formation. It is correlated with the Eagle Ford formation of Texas.

C)-2 San Vicente Formation

Name The San Vicente formation here is correspond to the San Vicente member of Maxwell et al. (1967) as cited above.

Type locality The type locality is the outcrops exposed about 3.2 km northwest of San Vicente situated about 10 km southwest of Boquillas del Carmen, and is well exposed along the Arroyo del Olan between San Vicente and La Union.

Distribution This formation is similarly distributed in the synclinal intermontane lowlands and in pediments as same as the Boquillas formation.

<u>Thickness</u> For the same reasons as the Boquillas formation, the thickness of this formation is very difficult to measure precisely, but about the same thickness (about 105 to 120 m) as the Big Bend National Park area is estimated in the Rio Bravo folded zone. Also about 120 m thickness in the northern part of the Sierra Santa Fé del Pino and about 88 m + thickness in the southern end of the Sierra de San Vicente are measured.

<u>Lithology</u> At the southern end of the Sierra de San Vicente, the formation is composed of three parts, that is, the bottom (about 22 m thick) of thin-bedded alternation of mudstone and marl in which the former is predominant, the overlying alternation (about 7 m thick) of chalk and thin-bedded black mudstone with pyrite nodules, and the top (about 59 m thick) of very thin-bedded chalk with abundant fossils. The upper San Vicente formation is not observed here.

About 10 km southwest of Ejido Jaboncillo, the upper San Vicente formation which yields an abundance of *Inoceramus undulatoplicatus* and consists of medium-bedded chalk is well exposed.

In the northern part of the Sierra Santa Fé del Pino, it is mainly composed of thin-bedded alternation of chalk and mudstone with sandstone in part, and generally accompanies nodular pyrite and well-reserved macrofossils.

<u>Environment</u> The San Vicente formation had presumably deposited under the neritic to littoral marine environment with an abundance of planktonic molluscs and benthonic faunae, and under a reducing condition with much organic material to yield pyrite nodules. Though the relation between the San Vicente and the Boquillas formations was reported to be unconformable, two formations seem to be concordant regarding beddings and have comparatively similar rock facies to each other, so that the gap during the unconformity is inferred to be very small, which is supported by the evidence of fossils.

Correlation From the San Vicente formation, Coniacian fossils such as *Didymotics, Inoceramus stantoni, Inoceramus* cf. *subquadratus*, etc., and Santonian fossils such as *Inoceramus* ex gr. *cycloides*, *Inoceramus undulatoplicatus*, etc. are found. Consequently it is possible that the San Vicente formation is of the Coniacian to Middle Santonian age, and correlated to the Austin formation of Texas (Maxwell et al. 1967).

C)-3 Pen Formation

Name It was introduced by Maxwell et al. (1967) in the Big Bend National Park.

Type locality The Pen formation was named at Chisos Pen in the northern Chisos mountain of the Big Bend National Park and is well exposed in the hilly areas of the southwest of La Union in the district.

Distribution The Pen formation occasionally forms hilly mountains and is distributed in the synclinal intermontane lowlands and in the desert-like lowlands of Valle de Sante Fé del Pino and Rio Bravo folded zone.

Thickness Since the formation is sporadically exposed in the desert-like lowlands and in the synclinal intermontane lowlands, and is frequently covered with the Quaternary sediments, the thickness is not obtained in this time. However, about 170 to 200 m thickness in the Rio Bravo folded zone Rivera, 1973) and about 65 to 210 m thickness in the Big Bend National Park (Maxwell et al. 1967) were reported.

Lithology The Pen formation is generally rich in pyrite nodule and rather brittle, consisting of the basal calcareous mudstone (about 15 m thick) interbedded with thin chalk, and overlying thick mudstone of dark gray to yellowish gray color with thin fine-grained sandstone and sandy to calcareous nodules. At the top of this formation, sandstone of 1.5 m thickness is locally recognized.

Environment The Pen formation which covers the San Vicente formation conformably is very rich in fine terrigenous clastics and pyrite nodules, and is assumed to have deposited in the shallow littoral sea under a reducing condition.

Correlation The Pen formation is considered to be of the Late Santonian to Early Campanian age, since *Inoceramus (Platyceramus) platinus, Placenticeras meeki, Delawarella danei,* etc. which are critical fossils of the age are abundantly found.

C)-4 Aguja Formation

Name and type locality The Aguja formation was initially defined by Adkins (1933) in the Sierra Aguja at the western corner of the Big Bend National Park of Texas, northwest of the survey district.

Distribution The Aguja formation is restrictedly distributed in the intermontane synclinal lowland between the Sierra de San Vicente and the Sierra de Harina, and in the hilly lowland located to the east of the Sierra de Hechiceros.

Thickness About 230 m thickness was reported in the north of the San Vicente. In the survey district, however, it is very difficult to obtain the thickness because of its sporadical distribution in the intermontane lowlands.

Lithology In the survey district, it crops out well in the southwest of Rancho Taraizos and around Rancho los Alamos, consisting of alternation of fine-grained sandstone and mudstone in which the former is predominant. However, the whole succession is not observed.

Environment The Aguja formation is assumed to have deposited under a very shallow littoral to lake condition in the period of epiorogenic uplift succeeded by Tertiary terrestrial environment.

Correlation The Aguja formation is considered to be of the Campanian.

III.2.3 Tertiary System

The Tertiary system is mostly composed of volcanic rocks, and is delineated to three volcanic areas of the south Sierra del Carmen, the Sierra de Hechiceiros and the Sierra de San José.

A) The South Sierra del Carmen Volcanics

The south Sierra del Carmen volcanics are mainly distributed in the south Sierra del Carmen, and comprises lower rhyolite, lower andesite, basalt, upper andesite and upper rhyolite in ascending order. Also small isolated distribution of dacite is recognized in the vicinity of Pico Puerto Rico. Those volcanic members are penetrated by various intrusives.

In the regional geologic map on the scale of 1:100,000, the upper and lower rhyolites are expressed together as Te-rh, and the upper and lower andesites as Te-an.

B) The Sierra de Hechiceros Volcanics

The Sierra de Hechiceros volcanics are widely distributed around the Sierra de Hechiceros, in the northwestern part of the district, and is divided into the lower and upper parts. The former is affected by the folding movement, while the latter is apparently not.

The lower Sierra de Hechiceros volcanics are composed of lower andesite, basalt and upper andesite; and the upper Sierra de Hachiceros volcanics are of rhyolite, basalt and dacite in ascending order. In the regional geologic map, the upper and lower andesites are expressed together as Te-an, and the upper and lower basalts are as Te-bs.

C) The Sierra de San José Volcanics

The Sierra de San José volcanics are widely distributed in the south of the Laguna del Guaje and the Laguna de Jaco, especially in the Sierra de San José and in the Sierra de San Antonio, and inferred to be younger than the others for the reason that some primary topographical characteristics of volcanoes are still remained in the southeastern corner of the district.

The volcanics are composed of tuffaceous sandstone, lower andesite, dacite, rhyolitic tuff, middle andesite, lower basalt, rhyolite, upper andesite and upper basalt in ascending order, though the lithology is only represented by one symbol in the regional geologic map on the scale of 1:100,000.

III.2.4 Intrusive Rocks

Based on the relation to main fold movement, intrusive rocks in the district are classified into three principal types such as (A) intrusive rocks before main folding stage, (B) intrusive rocks during main folding stage, and (C) intrusive rocks after main folding stage, and these are further subdivided according to occurrences, lithofacies, K-Ar age, and interrelation of intrusion for each other.

(A) Intrusive rocks before main folding stage

(A)-1 Hypabyssal intrusive rocks due to preceding igneous activity

The intrusive rocks which fall in this category are characteristic in showing the occurrence of sill, and consist of dolerite, rhyolite and granophyre. Those are found mainly in the Cerro Chalio area, and also in the Cerro de Minerva, El Volcan, Mina la Morena and the Sierra de Cruces areas.

Though some small bodies are found in pelitic rocks of the lower Cretaceous, the rocks of this type intrude generally the upper Cretaceous, particularly in thickly developed parts of it. These are penetrated by (A)-2, and considered to be introduced by igneous activity at the later stage of the geosynclinal process. No significant metallization is recognized.

(A)-2 Plutonic rocks from late Cretaceous to early Tertiary

Intrusive rocks of this type are distributed in the Cerro Chalio, the Cerro la Vasca and the Cerro de Minerva areas, and each of them consists of a stock-formed body showing the lithofacies change from gabbro to diorite.

The intrusive rocks are distributed on the line which runs in N-S direction, and show strong aeromagnetic anomalies. K-Ar age determination by these rocks shows $67.5 \times 52 \times 10^6$ years which indicates to be late Cretaceous to early Tertiary.

Although the intrusive rocks of this type are associated with thermal metamorphic recrystallization zones in the adjacent

Table III-2 Potassium-Argon Ages of Some Igneous Rocks

Area	Sample location	Sample No.	Rock name	Age in m.y.	Remarks
South Sierra del Carmen	Lava mesa on the mountain range	BRD62	Trachyandesite	4.4	fresh
	Alamo canyon	AR43, BRD36	Monzonite	27	carb., chl., seri, py.
	Logging road from Mina los Cojos	AR23	Anorthoclase andesite	37	chl.
	Rancho Santa Salome	AR27	Adamellite	39	weak chl. limo.
Northern end of the district	Agua Chile	G25	Altered rhyolite	33	weak chl.
	Northern part of Mina Mal Abrigo	G10	Andesite	43	weak chl., carb.
	Mina Mal Abrigo	G5	Dolerite	44	fresh
	Rico Etereo	G12	Trachyandesite	44	devitrified
Puerto Rico	Mina Puerto Rico	AR79	Altered diorite	32	seri., chl., limo.
Cerro Chalio	Cerro Chalio	BRD15	Gabbro	68	-
Cerro la Vasca	Cerro la Vasca	B106	Quartz monzonite	52	fresh
Sierra de Hechiceiros	13km west from Castillon	D29	Basalt	18	chl., limo.
	Rancho el Carricito	D3	Glassy andesite	27	carb.
	Picacho de Noche Buena	D6	Riebeckite-quartz porphyry	30	fresh
	5km southeast from Rancho Santa Anita	E138	Aegirineaugite andesite	45	fresh
	10km south from Castillon	D50	Aegirineaugite basalt	56	fresh
Cerro Blanco	South-southwest of Cerro Blanco	E155	Quartz porphyry	35	prehnite
El Volcan	El Volcan	AR15	Granite porphyry	4.2	fresh
Sierra de Cruces	Central part of Sierra de Cruces	Las Cruces	Syenite	5.2	weak chl.
Sierra de San José	8km north from Ejido el Alicante	D71	Hypersthene-augite andesite	35	-
Mina la Morena	IV phase survey area	SLM4	Altered dolerite	20	strong carb., chl.
	ditto	SLM2	Natrojarosite	-	-

areas, skarnization is generally weak, therefore, it is conceivable that they were introduced so called in "dry" condition. These rocks are accompanied with some mineralization of lead, zinc, and iron, but large-scale contact-type deposits have not been found.

(B) Intrusive rocks during main folding stage

The period of folding in Laramide orogeny is considered to be between 45 x 10^6 years (middle Eocene) and 35 x 10^6 years (early Oligocene).

During this period, intrusive igneous activities were taken place mainly in the Sierra del Carmen area, and massive to irregular pod-shaped fluorite deposits of significant scale were formed in some parts of the area.

(C) Intrusive rocks after main folding stage

(C)-1 Intrusive rocks from Oligocene to Miocene

Quartz syenite porphyry (27 - 27.2 x 10^6 years, late Oligocene) in the Sierra del Carmen area and altered rhyolite of dyke-form in the Sierra de Cruces area are included in this category.

The former is accompanied by thermal metamorphic zone associated with skarn minerals surrounding the rock, within which gold and silver mineralization is observed.

The latter is presumed to be produced with relation to the activity of rhyolite of the Sierra de San José volcanics.

(C)-2 Intrusive rocks from late Miocene to Pliocene

Sierra de Cruces complex (5.2 x 10^6 years, late Miocene) and granite porphyry in the El Volcan area (4.2 x 10^6 years, Pliocene) fall in this category, which are characterized by remarkable thermal metamorphic zones and skarn zones produced around the igneous bodies. The plutonic rocks which are presumed to be seated in depth in areas such as Mina la Morena and Picacho may belong to this type.

These rocks are composed of acidic intrusive rocks and accompanied by predominant iron deposits, manganese deposits, and significant copper showings, which build up the most preponderant concentration of base metals with silver in the project district.

III.2.5 Quaternary System

The Quarternary system is mainly recognized in the synclinal intermontane lowlands and in desert-like lowlands, comprising evapolite and fine clastic sediments in bolson such as the Laguna del Guaje, the Laguna de Jaco, etc., and is usually predominant in conglomerate accompanied with sandstone and mudstone which can be divided into some groups by terraces, occurrences and the constituents. Some of them may have to be included in the upper Tertiary, but they are treated together as the Quarternary system in this report, because it is out of the purpose.

III.3 Geological Structure

According to the published data, the survey district lies within the southern extension of the Front Range which longitudinally traverses the North American Continent from Canada to Texas, having abundant folds and faults under compressive conditions. Also it is thought that the district is partly in the eastern extension of the Texas zone which continues from California and is accompanied with many intrusive igneous activities, faults and folds.

From the structural assortment of trend, distribution, intensity and frequency of folds, faults, intrusives and domes, the district and its surroundings are divided into following five zones: the Marathon zone, the Sierra del Carmen zone, the Rio Bravo folded zone, the Pino-Monclova zone and the Mula-Mojade zone. Structurely speaking, the Marathon zone and the Sierra del Carmen zone are situated at the western end of the Coastal Plain of Mexican Gulf; the Rio Bravo folded zone and the Sierra del Carmen zone are in the southeastern extension of the Texas zone; the Rio Bravo folded zone and the Pino-Monclover zone are included in the Front Range; and the Mula-Mojada zone also lies in the Front Range, but is somewhat structurely different from the former zones as described later. The Rio Bravo folded zone where the two tectonic zones overlap each other is characterized by a strong deformation and intrusive igneous activities.

The Marathon Zone

The Marathon zone bounded on the Sierra del Carmen zone on the south by the EW-trending alignment of the intrusive igneous rocks in the northern Sierra del Carmen, is mainly interpreted by the LANDSAT image analysis, since the zone is mainly in Texas, U.S.A. and in the northern part of the Sierra del Burro which are out of present regional survey district. It is characterized by the absence of the folds and faults of the Laramide orogeny, and by the presence of dendritic drainage patterns and very gently inclined cuestas.

In the Marathon region in U.S.A. an almost rectangular block called Marathon uplift, which is outlined by the NNW-SSE and ENE-WSW-trending lineaments, is recognized, where distinct NE-SE-trending old structures, mostly folds, are distinctly developed.

The Marathon zone is situated in the east of the Fronte Range and at the western end of the Coastal Plain of Mexican Gulf, and is considered to be comparatively stable area to the Laramide orogenic movement.

The Rio Bravo Folded Zone

The Rio Bravo folded zone here is enclosed by following lines:
the eastern line is obtained by connecting a point about 7 km south-southwest of La Linda to Mina de la Encantada via the west of Mina Puerto Rico, by which the zone is bounded on the Sierra del Carmen zone; the southern line is bounded on the Pino-Monclover zone, and ties the Sierra los Altares to Mina de la Encantada via the north of the Sierra de Alazan and the south of Ejido San Miguel, which was previously called the Los Alazanes tectonic line; and the northern line is the Rio Bravo, River, national border to U.S.A.

The los Alazanes tectonic line is considered to be structural break, and the eastern limits may be echelon faults on the western escarpment of the Sierra del Carmen.

The zone is characterized by compressive structures of asymmetrical folds accompanied with fold-faults trending NNW-SSE and their conjugated faults trending ENE-WSW. Also many dome structures caused by intrusive rocks and basin structures are observed.

Fold ;

Most of all folds having the trend of NNW-SSE in this district are asymmetical and assumed to have been formed by the Laramide orogeny from Late Cretaceous to Late Eocene. Usually the eastern wings are steeply inclind, while the western wings form gentle cuestas in the west of the Arroyo del Olan. In the east of it, by contrast, the eastern wings form gently inclined cuestas. The wavelength of the folds is comparatively short(about 5 to 10 km long). The anticlines usually form mountain ranges, and the followings are principal: the Cuesta los Alazanes anticline, the Sierra de Alazen anticline, the Juntas anticline, the Harina anticline, the Sierra de San Vicente anticline and the Cerro del Veinte anticline. The synclines are usually found in the intermontane lowlands and the followings are relatively large: the Alazan syncline, the Piedritas syncline, the Subiran syncline, the Arroyo del Olan syncline, etc. These main folds are sometimes complexed with the subsidiary folds with the same trend.

Fault

In the northern half of the zone where the Cretaceous formations are mainly distributed, conjugated fault system of NNW-SSE and ENE-WSW trends, in which the former is almost parallel to the main fold-axes and the other is perpendicular to it, are predominant and assumed to have been formed under the compressive condition during the Laramide orogeny. In the southern half where the intrusive igneous activities are intensified, NS and EW-trending faults are recognized in addition to the NNW-SSE and ENE-WSW-trending ones. The NS and EW systems are assumed to have been formed by the post-Laramide movement and are of normal type.

The fold faults are always recognized at the steeply inclined side of the asymmetrical folds and apparently the displacement of the fault is usually maximum at the center. The followings are comparatively large:

the El Caballo fault in the west of Rancho el Caballo, the Juntas fault in the east of the Sierra de Juntas, the Harina fault in the east of the Sierra de Harina, San Vicente fault in the east of the Sierra de San Vicente, etc.

The faults conjugated with the fold faults are usually short, but some ones are traceable as long as about 15 km as in the case of the fault in the Cerro del Veinte. Though the displacement of the conjugated faults is relatively small, the drainage pattern and density are highly controlled by them and fluorite deposits are frequently formed in these faults, especially in the anticlinal parts.

Also NS, EW and NNW-SSE faults which are apparently free from the Laramide orogenic movement are observed. They are mostly of normal type.

Other Structures (Basin and Dome Structures)

An elliptical-shaped basin structure which has the major axis of about 25 km and the minor axis of about 10 km is recognized in the intermontane lowland around La Union, where the upper Cretaceous formations are dominantly distributed, and frequently intruded by sills and radial dike swarms of basic hyabyssal rocks and by diorite stocks and sills.

Three dome structures accompaning stock-form intrusives are recognized in the Cerro la Vasca, the Cerro Chalio and the Cerro Tecoscana, where the Cerro la Vasca dome is caused by quartz monzonite, and others by dioritic coarse-grained intrusive rocks. The Cerro la Vasca and the Cerro Chalio domes are of oval shape, and the major axes are in parallel to the fold axes of the Laramide orogeny. The two domes, however, seem to have been free from the influences of the fold movement, in spite of the fact that the zone has been strongly affected by the fold movement. The intrusives may have played as a rigid resistive body against the compressive stress of the Laramide orogeny.

III.4 Historical Geology

As the result of Nevadan orogenic movement from late Jurassic to early Cretaceous, Cordilleran geanticline was formed by the upheaval of the western part of North American Continent, which resulted in the subsidence of Rocky miogeosyncline and Mexican miogeosyncline.

It is considered that the transgression at this time, encroaching from the Gulf of Mexico, extended widely over the southwestern and the central parts of the United States of America (Smith, 1970).

Submerged region from northern Mexico to inland of the continent was relatievely stable having the topographical relieves in places, so that the sediments of the region contain limestone as well as neritic red bed and evaporite. These are deposited in the basins between the highlands.

By the end of the Neocomian age of early Cretaneous, the basins were filled with these sediments, and limestone is predominantly distributed over the whole region except alternation of terrestrial clastics and calcareous sediments surrounding the highlands.

From the Aptian to Albian age, periodical marine regression interrupted the sedimentation of limestone by intermittent supply of terrestrial clastics from the north and south. The frequency of such repetition became increased from the Cenomanian age to the Campanian age of the upper Cretaceous.

Thus the formations from the Neocomian to Albian age were deposited mainly in the developing stage of Mexican geosyncline, though the formations indicating the regression are also intercalated. On the contrary, the formations from the Cenomanian to the Campanian age of the upper Cretaceous consist of the alternation of terrestrial clastics and neritic calcareous sediments. The sedimentary rocks overlying these formations show the facies of lacustrine sediments intercalating coal seams. Therefore, it can be said that the upper Cretaceous system shows a sedimentary facies in later stage of the Mexican geosyncline.

The surveyed district situated in northern Coahuila having such histrical background covers the Sabinas Bay of the late Jurassic put between two peninsulas, Tamaulipas on the east and Coahuila on the west, and its bay head (Imlay, 1943). As an evidence of this, the exposures of metamorphic rocks (inferred to be Palaeozoic) which can be considered to be the basement in the surveyed district were found at the western piedmont of the Sierra del Carmen in the northern part of the district.

Following the subsidence which continued until late Cretaceous, the district became subjected to the influence of the Laramide orogeny from late Cretaceous to early Tertiary. In the Cretaceous system, great compressive stresses formed asymmetric foldings and fold-faults resulting in the emergence.

The main folded zone in the western foot of the Sierra del Carmen is bounded on the east by the Las Norias tectonic zone which runs in the NNW-SSE direction. The east side of this tectonic zone is characterized by repetition of relatively gentle anticlines and synclines, which shifts to the coastal plain on the west of the Gulf. On the contrary, strong folding structures were developed on the western side.

From the result of K-Ar dating and the influence of folding afforded to the rock bodies in which the samples for measurement were taken, the period of the folding formed by the orogeny is estimated to be in the range between 45×10^6 and 35×10^6 years. The northern part of the district was under the influence of the Texas zone represented by brisk igneous activities, which formed characteristic folds of short wave length and numerous intrusive rock bodies in the area. During the late Tertiary, the whole district underwent active acidic igneous activities, and normal faults were formed under tensional stresses. It is also likely that pre-existed faults were reactivated.

III.5 Ore Deposits

A number of ore deposits distributed in the district are classified based on their principal ore minerals into fluorite deposit, silver -bearing copper-lead-zinc deposit, gold-silver deposit, and iron deposit. These are further subdivided on the basis of the mode of occurrence and the time of ore deposition.

III.5.1 Fluorite Deposit

The period of activity of igneous rock and formation of geological structure inferred to be related with the localization of the fluorite mineralization are extended over from late Cretaceous to late Tertiary. Also fluorite is accompanied as gangue mineral in many other types of deposits except iron deposit. Therefore, it is considered that the whole project district were under the geochemical environment for considerably long time in which fluorine element was liable to be supplied.

Fluorite deposits are mainly distributed in the northern half of the survey district, but some scattered occurrences are found in Cerro la Vasca and El Volcan areas in the southern half.

The deposits are classified based on their form into three types as follows:

(1) Massive to irregular chimney type

(2) Manto type

(3) Vein type

The deposits of type (1) are largest in scale, and most of the deposits which had been worked and being operated until present falls in this category.

The ore deposits are associated with trachytic to rhyolitic intrusives of alkaline rock series and partly with adamellite or monzonite, and occur in limestone as irregular masses along the contacts between intrusive rocks and limestone beds. Calcite is the pricipal gangue mineral.

The temperature of deposition indicated by the fluid inclusion study is generally higher than that of the manto type mentioned below, and some are reported to be higher than 350°C. The ore bearing horizons of this type vary more diversely than the manto type, extending from the Sue Peaks formation to the Del Rio formation. Ore shoots are generally formed underneath the pelitic beds.

Manto-type fluorite deposits are small, and of layered or irregular assemblage of network veins, preferentially localized at the top of the Santa Elena formation.

Numerous old workings more than one hundred are found in the Río Bravo folded zone and some are also found on the northeast and the west of the Carmen dome in Sierra del Carmen area.

Ore mineral consists of fluorite generally colorless, transparent to white and partly purplish in color accompanied by calcite as gangue mineral.

The temperature of the deposition indicated by the fluid inclusion study was about 150°C in general, which is lower than the massive and irregular chimney type. It is an important feature that there is no significant volcanic activity in the area which is distributed by this type deposits, especially in the Río Bravo folded zone.

It is considered that the fluorite deposits of this type generally have low economic value because of the remote location of deposits from igneous rocks, and because of low temperature of ore deposition, which presumably resulted in the formation of poor deposits compared with massive and irregular chimney type described above.

Lea and Le India deposits in El Volcan area belong to type (3). The deposits are formed in silicified parts arranged in echelon in relatively persistent fault zones. The veins are found in the Pen and the San Vicente formations, which are for upper horizons compared with those of the other types. The age of mineralization is inferred to be Pliocene or later. The deposits of this type are characterized by abundant quartz as gangue mineral and generally of low grade. The distribution of the deposits is controlled by silicified zones and fault zones which are developed in younger igneous rocks and their surroundings.

III.5.2 Silver-Bearing Copper, Lead and Zinc Deposit

Numerous ore deposits and showings of this type are found in the district as shown below.

Oxidized ore deposits along the Las Norias fault (ore deposits such as Puerto Rico, San José, Papicuano, Venos, and other many showings).

Oxidized ore deposits surrounding the Cerro de Minerva dome (ore deposits such as Mesquite, Minerva, Gloría y Lucía, Gloria, and Estellella).

Oxidized ore deposits in El Volcan area (Collan deposit and El Volcan deposit).

Oxidized ore deposits in Mina la Morena area (ore deposits such as La Morena, El Refugio, and La Diaña).

Oxidized ore deposits in Sierra de Cruces area (ore deposits around the Santa Elena anticline, Libertad, and Quebrada).

Although El Volcan deposit was worked principally for manganese, it was classified here due to relatively high grade of copper, lead, and zinc.

The ore deposits are grouped based on their mode of occurrence into type a (vein-type) and type b (contact-type). The latter is further subdivided based on the relation with folding in the Laramide orgeny into two types such as type b-1 (the deposit related with pre-folding intrusive rocks) and type b-2 (the deposit related with post-folding intrusive rocks).

(a) Vein-type silver bearing oxidized lead and zinc ore deposit

All deposits and showings in Puerto Rico area, Collan deposit, La Morena deposit, El Refugio deposit, and the deposits in the Santa Elena anticline area belong to this type. These deposits are located mostly in the large-scale geological structures such as anticlines and fold-faults brought by the Laramide orgeny, and Las Norias tectonic zone. The ore deposits were formed after the Laramide orgeny. Because the anticlinal structure deformed by the intrusion of late Miocene played an important role on the ore deposition as shown in the Santa Elena anticline, and because the Collan deposit is localized in the fault system which cut the Pliocene intrusive rocks, it is assumed that the mineralization continued up to Pliocene. Except for the Collan and La Diana deposits which lies in the Aurora formation, all other deposits are found in the Cupido formation or lower and most of the major deposits are also in the Cupido formation. These facts indicate that this formation is the essential factor to locate the ores.

As the cause of this penomenon, it is considered that the Cupido formation is the first principal calcareous rock encountered by ascending ore solution, and it is also inferred that the salt-rich evaporites represented by gypsum beds indirectly made contribution to the ore deposition.

(b)-1 Contact-type silver bearing lead and zinc deposit of pre-folding period

The deposits and ore showings in and around the Cerro de Minerva area fall in this type. These deposits and showings are considered to be brought by intrusive rocks which belong to Type A-2 (described before) possibly intruded in so-called "dry condition", and they are small in scale and low in grade. It can be said, therefore, that economic importance of this type is very low.

(b)-2 Contact-type-silver bearing copper, lead and zinc deposit of post-folding period

The deposits such as El Volean, La Diana, Libertad, and Quebrada belong to this type. These deposits are considered to be brought by plutonic intrusive rocks which were classified as type C-2 (described before). The rocks are mostly acidic and accompanied by skarn zones and recrystallized zones surrounding them. It is inferred that these rocks were rich in volatile components compared with those introducing the deposits of type (b)-1.

Deposits of this type are remained unexplored in this district, especially in the case that the intrusive rocks are seated in depth. It is considered to be necessary to investigate the potentiality of ore deposition by systematic exploration. The mineralized zones adjacent to La Diana deposit surveyed in the final phase belong to this type. The deposits in Mina la Morena area including the mineralized zones around La Diana deposit will be described in detail in other section.

III.5.3 Gold and Silver Deposit

This type is found only in the South Sierra del Carmen area, which includes such known ore deposits as Fronteriza, Teresita, and Juarez. These deposits are considered to have been formed with relation to quartz syenite porphyry of C-1 type previously mentioned, and occur in skarn zones and recrystallized zones adjacent to the intrusive rocks. The deposits which have been discovered so far are relatively small in size and generally low in grade. All these are low in economic importance.

III.5.4 Iron Ore Deposit

The deposits of this type alone have been explored and developed systematically and in large scale in the project district.

Two sorts of iron ore deposits, (a) orthomagmatic iron ore deposit and (b) contact-type iron ore deposit, are found in the whole project district. The major deposits belong to (a), and are distributed in the Sierra de Cruces area.

The deposits in the Sierra de Cruces area consist of iron oxide with lenticular shape which was concentrated in the later stage of the intrusion of the Sierra de Cruces complex classified as C-2, and was intruded along the weak structures which had been formed in the surrounding area of the complex. In some places, skarn zones with zonal arrangement along the margin of the ore deposits were observed. In the area, fourteen outcrops have been found together with several magnetic anomalies which are assumed to indicate iron ore deposits. Among these, two deposits have been hitherto explored and developed. The one is located on the north of the Sierra de Cruces complex and operated by Minera del Norte S.A. The other is on the east of the complex and explored by Hojalata y Lámina S.A.

III.5.5 Summary

The ore deposits distributed in the district are divided into three kinds such as fluorite deposit, silver-bearing copper, lead and zinc deposit, and iron ore deposit.

The principles for exploration of these deposits are considered as follows:

(1) Fluorite deposit

While the deposits are distributed throughout the district, most of them are found to be concentrated in the northern half. Among the deposits, the largest and most productive deposits belong to massive and irregular chimney type, which are localized along the contact between trachytic to rhyolitic intrusives of alkaline rock series and the limestone beds. As this type, deposits of Agua Chile, Quatro Palmas and La Borada are known at present. These are distributed in the Sierra del Carmen zone structurally. The development of igneous activities of alkaline rock series in the area strongly suggests the genetical relationship with the Texas zone.

Therefore, the exploration of fluorite deposits in the district will have to be directed to the Sierra del Carmen zone as the center. In this case, the Carmen dome will be designated with the first priority as potential target providing similar geological conditions. However, because the Carmen dome is a fairly large structure having a diameter of 10 kilometers, it is anticipated that difficulties of locating the position of deep-seated intrusive rocks and the mineralized zones will be encountered.

(2) Silver-bearing copper, lead, and zinc deposit

Silver and base metal deposits in the district are divided on the basis of the locus, the time relation with tectonic movement, and interrelation with igneous activities into three types. Among these, the types provided with the following geological conditions are considered to be the targets for future exploration.

(a) Relating igneous activity

The intrusive rocks of late Miocene to Pliocene distributed in the district are commonly acidic, and accompanied with noticeable skarn zones and recrystallized zones of limestone together with hydrothermal alteration and mineralization.

The Sierra de Cruces complex (5.2×10^6 years) and El Volcan granite porphyry (4.2×10^6 years) belong to the intrusive rocks of this type. The age of the intrusive rocks which are assumed to be seated in depth at Mina la Diana mineralized zone in the Mina la Morena area (exploration target in the final phase) and at the Picacho area in the southern part of the Sierra de Cruces is estimated to be contemporaneous with those mentioned above.

(b) Locus of the ore deposition

The main loci of vein-type deposits in the district are large-scale geological structures such as anticlines and fold-faults brought by the Laramide orogeny, Las Norias tectonic zone, etc. The age of ore deposition is after the oregeny, though the younger limit is yet unknown. However, as shown in the Santa Elena anticline, the anticlinal structures which were deformed by the intrusion of late Miocene play an important role in the formation of ore deposits. Also, the Collan deposit is localized in the fault system which cuts the Pliocene intrusive rocks. These evidences indicate that the mineralization continued to Pliocene. Except for the Collan and La Diana deposits which are formed in the Aurora formation, all other deposits are found in the Cupido formation. The most essential cause of this fact would be that the Cupido formation was the first principal calcareous rock encountered by ascending ore solution. It is also considered that the evaporites in the formation might indirectly contributed to the ore deposition.

(3) Iron deposit

From Mina Hercules which has been developed systematically and in large scale as a productive mine in the surveyed district to the eastern periphery of the Sierra de Cruces intrusive complex, fourteen outcrops have been found together with several magnetic anomalies assumed to indicate iron ore deposits. However, all these are owned by private companies, having already been explored and developed, and no special considerations have been made as targets for future work.

III.6 Ore Deposit in Mina la Morena Area

Ore deposits in Mina la Morena area are observed at two localities such as the northeastern Sierra la Morena mineralized zone represented by Mina la Morena and Mina el Refugio, and the central Sierra la Morena mineralized zone which contains a recrystallized zone of limestone and Mina la Diana. The description are made in the following.

III.6.1 Northeastern Part of the Sierra la Morena

The mineralized and altered zones are localized along the faults extending in N 60° W direction such as Mina la Morena and el Refugio, in which medium grade argillization and pyrite dissemination are observed, and recrystallization took place along the faults over the area 200 m in width and 1,200 m in length in the hilly mountain at the foot of northeastern slope of the Sierra la Morena.

Among these, the principal mineralizations are found in Mina la Morena and in Mina el Refugio.

In Mina la Morena, the vein-type silver-bearing lead and zinc deposits filling the faults mentioned above and small fissures derived from them have been explored by sinking small-scale shafts and by surface trenchings.

The ore deposit consists of quartz-calcite veins associated with oxidized ore 0.3 - 1.0 m in width and about 20 m in length which fills faults and small fissures developed in the alternation of black shale and marl with intervening thin beds and veinlets of gypsum in the Cupido formation. The ore contains black fine-grained pyrite and marcasite, and also a black mineral which is likely to be manganese dioxide.

Some scattered native sulphur is observed in gangue minerals.

Mina el Refugio is situated about 1 km to the southeast of Mina la Morena, and el Refugio fault runs directly north of the mine. Like to Mina la Morena, the deposit consists of quartz-calcite veins associated with oxidized ore filling the small fissures.

The assay result of samples taken from the stockpile in both mines were several ~ 299 g/T Ag, 0.5%±Cu, 0.n% ~ 3.65% Pb, and 0.n% ~24% Zn.

It is presumed that these deposits were formed by the hydrothermal solution ascended along the faults such as Mina la Morena and el Refugio being developed along the axis of the Sierra la Morena anticlinorium. Although these deposits which have been found so far are small in scale and poor in grade, they are positioned in an extention of the central mineralized zone, and both are included in the same geochemical anomaly zone. Therefore, the relation of these two mineralized zones is worthy of notice.

III.6.2 Central Part of the Sierra la Morena

Geological structure

The area is, as a whole, located in the southwestern wing of the Sierra la Morena anticlinorium. When observed in detail, however, the primary structure is superimposed by the folding structures of second and third degree in the same direction and another folding axis which crosses at right angles with them extending in NE-SW direction.

Recrystallized zone

The mineralized zones are distributed in and around of the recrystallized zone of limestone approximately elliptical in shape with long axis of about 2.4 km and short axis of about 1.5 km extending in NE-SW direction within an unusual topography of depressed low land situated in the central part of the Sierra la Morena.

The recrystallized limestone of the Aurora formation has a core of saccharoidal limestone (1.7 km x 1.1 km) surrounded by the halo of microcrystalline limestone. In some part of the core, veins of garnet, quartz, and calcite, and porphyroblastic large crystal of garnet are found. It is also associated with wollastonite and actinolite in small amount, and silicification is commonly observed.

The mineralized zone

The mineralized zone is divided into six groups on the basis of their

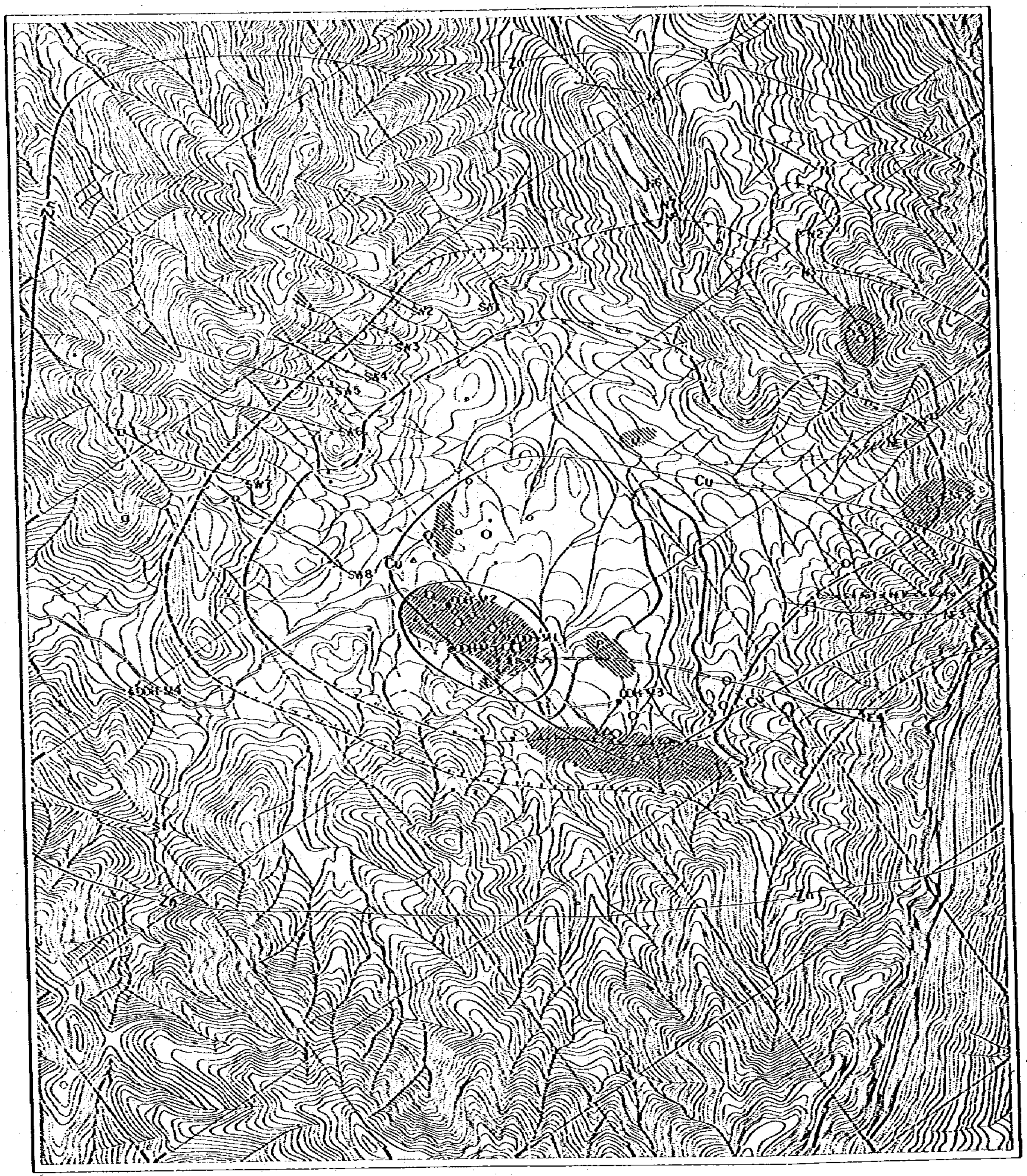
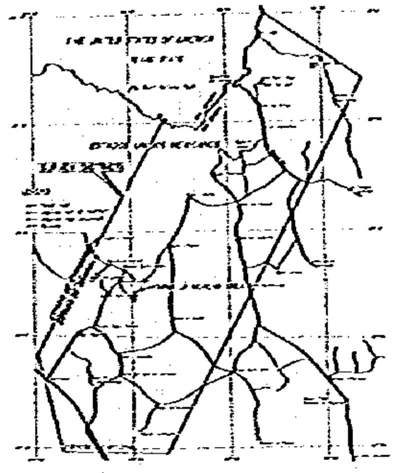


Fig. Ⅲ-2

GEOLOGICAL SURVEY
OF
THE COAHUILA AREA, NORTHERN MEXICO

INTERPRETATION MAP OF THE MINA LA MORENA AREA



JAPAN INTERNATIONAL COOPERATION AGENCY AND
METAL MINING AGENCY OF JAPAN, GOVERNMENT OF JAPAN
COLLABORATION WITH
CONSEJO DE RECURSOS MINERALES DE MEXICO
FEBRUARY 1979

LEGEND

- Stock mineral-bearing recrystallized zone
- Saccharoidal recrystallized zone
- Fine-grained recrystallized zone
- High copper-ratio zone
- High zinc-ratio zone
- Vein and its number
- Mineralized zone and its number
- IP anomaly and its symbol
- O High copper-ratio ore
- Δ High zinc-ratio ore
- □ High silver-ratio ore

geographical distribution such as the north, northeast, east, center, southwest, and south. (See Fig. III-2).

(1) The north group

The mineralization consists of a number of vein- and manto-types hematite and calcite deposits localized in the microcrystalline recrystallized zone and the fresh limestone outside of it, in which eight ore bodies such as N1, N2 ...... N8 are the principal (cf. The Report of Phase IV).

The vein-type deposits are lenticular in shape filling the fractured zones. The size of a lens is 0.3 - 0.8 m in width and 10 - 20 m in length, but an intermittent continuation as long as 300 m has been confirmed. It was observed that a laminated marly part, 15 m wide, was mineralized in a vein type deposit, which seems to be selectively replaced in that part. This laminated marly part consists of calcite and quartz veinlets which filled the brecciated part developed in the form of lattice work, so that the lower limit of the vein is distinctly bounded by the contact plane with the non-mineralized limestone bed.

The manto-type deposit replaced the marly part interbedded in the limestone, which continues as long as about 150 m with the width of 0.5 - 2.0 m. The ore minerals are hematite and hydrous iron oxide associated with small amount of calcite.

The assay result of the smaples taken from these deposits are as follows:

Tip sample containing green copper mineral of the most predominant network-vein-type N 4 deposit showed 65.7 g/T Ag, 3.11% Cu, 0.02% Pb, 2.21% Zn, while the sample in which no green copper mineral was observed showed 10.0 g/T Ag, 0.05% Cu, 0.02% Pb, and 0.33% Zn. The samples taken from the manto-type deposits were lower than these.

As shown in the above, the north group presents a weak mineralization in general, in which the grade of ore is low. As to N 4 ore body, partial swell of the vein might have taken place at the contact of the marly bed with fault fracture zone.

(2) The northeast group

This group consists of relatively high-grade ore veins localized in the fault and fractured zone including the La Diana ore body. Among these, four veins such as NE 1 ..... NE 4 continue well to be traceable, which develop mainly in the microcrystalline limestone.

These ore bodies consist of small ore vein groups arranged in echelon or in parallel, and unit ore vein have the width of 0.3 - 4 m and 10 - 350 m in length.

The gangue minerals consist mainly of quartz and calcite. As the ore minerals, hematite and green copper mineral are observed megascopically, while under the microscope, native copper, native silver, cerargyrite, bromyrite, tenorite, and cuprite were observed.

The assay result of the tip samples from these veins varies to a great extent, in which high-grade part showed 1 - 3 g/T Au, 100 - 500 g/T Ag (max. 9,090 g/T), 1 - 16% Cu, 0.0n% Pb, and 0.n% Zn.

Thus the northeast group consists of veins which filled fault fracture zone showing relatively good continuation.

(3) The east group

The mineralized zone is situated in the microcrystalline recrystallized zone at the eastern margin of the recrystallized zone extending in N 50° E for 350 m with the width of 100 m, in which a number of calcite-quartz-hematite veinlets associated with green copper mineral are distributed in parallel (some manto-type and irregular massive-type are also observed) constituting the mineralized zone. There are fifteen principal ore bodies, and the size of unit ore body varies from 0.3 m to 4 m in width and from 10 m to 120 m in length.

The ore minerals are hematite, limonite, and green copper minerals. Gangue minerals are quartz, calcite, and gypsum, etc. Cuprite, tenorite, and chalcocite were observed under the microscope.

The assay result of the samples from the ore vein and from the stockpile showed the range of grades as follows: Tr ~ 2.9 g/T Au, several ~ 500 g/T Ag, 0.n ~ 8% Cu, 0.0n% Pb, 0.n ~ 21% Zn. Zinc silicate mineral was identified in a high-grade zinc ore.

(4) The central group

The south-central part of the saccharoidal recrystallized zone is the skarn-bearing recrystallized zone characterized by garnet-calcite-quartz vein, and small amount of porphyroblastic garnet, wollstonite, and actionlite. The extent of this zone is 150 m in width and 350 m in length, in which 15 NE-trending hematite-calcite-quartz veins are distributed. While most of these veins have steep dip and same strike, some cross veins and manto-type ore bodies are found.

Most of the veins are several dozen centimeters in width and several dozen meters in length, though some larger veins were traced as long as 100 m attaining several meters in width.

The ore minerals observed on the surface consist mainly of iron oxide ore associated with green copper minerals. Under the microscope, hematite, cuprite, tenorite, native copper, and chalcocite are observed. The main gangue minerals consist of calcite, quartz, fluorite, and gypsum associated with such skarn minerals as garnet, wollstonite, and actinolite. Beside these, sericite and chlorite are present.

In drill cores taken from the lower extention of the ore veins intersected by the drilling carried out in the mineralized zone, primary sulfide minerals such as pyrite, pyrrhotite, chalcopyrite, tetrahedrite, polybasite, and galena, and small amount of cerargyrite and bromyrite were observed beside oxidized minerals.

Assay results were in the order of 1 g/T Au, several tens to several hundred g/T Ag, several percent of copper, 0.0n% Pb, and 0.n% Zn.

(5) The southwestern group and the south group

In the microcrystalline recrystallized zone and in its outer zone of nonrecrystallization in which relatively frequent occurrence of faults is observed, the vein-type to manto-type oxidized ore deposits are distributed in numbers controlled by fault fracture zone, fissure, and bedding plane. Among these, eight ore bodies have been found to be significant.

In a zone of non-recrystallization to the south of the recrystallized zone, a fault fracture filled with calcite-quartz vein is found being locally mineralized.

The assay result of the samples taken from the veins in the southwestern and the south groups showed the value in the order such as tr. Au, several g/T Ag, 0.n ~ 0.0n% in Cu, Pb, and Zn, indicating proor grade of the veins in general.

From the outlook of the six groups of mineralized zone, it is indicated that those of the center, the east, and the northeast are more predominant than other groups in the size of mineralization, hydrothermal alteration, and in thermal metamorphism. The geochemical anomalies detected by the geochemical survey conducted in Phase III have the tendency, on the whole, to connect to the mineralized zone in the northeastern part of the Sierra la Morena including these three groups.

The result of drilling

In Phase IV, three holes out of five drill holes bored in this area were purposed to investigate the mineralized zone of the center group. The results are as follows:

In DDH-M1, a manto-type oxide ore body was encountered at the depth between 12.05 m and 16.65 m. The average grade of the whole range were 2.2 g/T Au, 161.3 g/T Ag, 2.51% Cu, 0.01% Pb, and 0.17% Zn. Beside these, eleven steeply dipping veins were intersected, the width of which were generally small such as 1 - 5 cm except for one which was 1.5 m wide.

In DDH-M2, a number of veins were encountered. Among those, the principal veins are listed in the following table.

Range (m)	Width (m)	Au g/T	Ag g/T	Cu %	Pb %	Zn %	
120.50-124.80	3.0	8.3	94.5	0.72	0.02	0.06	Oxide ore
124.95-128.50	1.8	2.1	220.4	7.83	0.02	0.10	"
148.70-149.90	0.6	tr	15.7	0.18	0.01	0.03	Quartz, calcite, pyrite
161.65-163.80	1.07	tr	62.9	0.60	0.00	0.09	
164.20-165.75	0.78	0.7	55.0	0.97	0.02	0.08	

In DDH-M2, it was characteristic that a number of iron sulfide veins were concentrated between 140 m and 220 m. The width of the veins were in the ranges of several cm to thirty cm and ore grade were tr. ~ 1 g/T Au, several ~ several tens g/T Ag, 0.0n ~ 1.78% Cu, 0.0n% Pb, and 0.0n ~ 2.81% Zn, thus being generally low in grade.

DDH-M5 was sunk to get more exact information on the shape of the ore body intersected at the depth between 160.50 m and 165.75.

The calcareous sedimentary rocks observed in these three holes had been completely recrystallized being 0.1 ~ 0.2 mm in grain size, which was more fine-grained in marly part. Skarnization is generally weak, and skarn minerals such as hedenbergite, wollstonite, diopside, garnet, epidote, zoisite, and actinolite are partly observed.

Among these, only garnet can be confirmed megascopically, and other minerals are observed in a small amount in thin sections. These skarn minerals are found in the vein or in its vicinity. Large porphyroblastic crystals of garnet as large as 5 cm in diameter were observed in the drill holes such as DDH-M2 (156.50 m) and DDH-M5 (125.75 m).

Hydrothermal alteration such as carbonatization, silicification, sericitization, and chloritization are commonly observed. Among these, silicification and carbonatization are observed commonly in mineralized part in every hole, whereas sericitization is remarkable in the vicinity of sericite-quartz rock pieces which seem to be derived from igneous rock and are contained in the veins encountered in DDH-M2 (125.40 m) and DDH-M5 (147.50 - 156.75 m).

These effects of alteration are limited within the veins, fracture zones accompanied by coarse-grained calcite, and at the adjacent wall rock to the vein, and can not be found broadly in the country rock. It is observed that chlorite, calcite, quartz, iron hydroxide, pyrite, and sericite are formed along the crack of the porphyroblastic large crystals of garnet. This fact leads to the conception that the garnet which had been formed at the stage of skarnization was retrogressively altered in hydrothermal stage.

As can be understood from the above, the information of the veins obtained from the drilling indicates that the size, the extent of hydrothermal alteration, and ore grade of mineralized zone observed on the surface maintains these preponderant features even more toward the depths. A kind of rock pieces presumed to be originated in the igneous rock is contained in some part of the vein, and it was found that relatively rich ore formed in such part.

Consideration

The country rock of the deposits in the area is the limestone of the Aurora formation and main loci are NE-trending fault fracture zones and fissures developed in it. In some part, however, manto-type and irregular massive-type deposits are found along pelitic beds intercalated in the limestone.

On the other hand, the results of regional geological survey conducted throughout the whole district indicate that the Cupido formation is the most favorable ore horizon. The results of diamond drilling also indicate that the mineralized zones tend to be predominantly developed in the depth.

Putting all information together, it would be concluded that the future exploration should be directed to the confirmation of the extention of main mineralized zones to the horizon of the Cupido formation.

For this purpose, it is required that the drilling is to be planned to reach the depth of 600 m to 800 m from the surface.