NO. 13

REPORT ON GEOLOGICAL SURVEY

OF

METAL MINING AGENCY OF JAPAN

JAPAN INTERNATIONAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

Errata

Page	Line	Error	Correct
I	2nd from the top	district in the	district of the
III	13th " "	remarkabley	remarkably
IV	15th " "	*potassium*	potash
11	10th " "	grains	grasses
30	13th " "	and the upper	and upper
39	12th " "	*upper-most*	uppermost
47	6th " "	surveydistrict	survey district
49	5th from the bottom	rangeis	range
50	6th from the top	*in latest*	*in the latest*
52	5th " "	occurred	produced
53	6th from the botton	ro rhyolite	to rhyolite
68	9th from the top	*potash-rhyolite*	*potash rhyolite*
"	3rd from the bottom	" "	" "
"	4th " "	" "	" "
69	5th " "	*ana a*	*and a*
74	12th " "	is working	are working
76	5th " "	idstribution	distribution
78	9th from the top	*outlock*	*outlook*
83	*1st from the bottom*	deveroped	developed
84	14th from the top	Pachuga	Pechuga
"	8th from the bottom	"	"
88	3rd " "	potassium	potash
92	4th from the top	"	"

ESTADOS UNIDOS MEXICANOS

REPORT ON GEOLOGICAL SURVEY OF THE PACHUCA-ZIMAPAN AREA, CENTRAL MEXICO

PHASE I

PHOTOGEOLOGICAL INTERPRETATION
GEOLOGICAL SURVEY

FEBRUARY 1980

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 Pachuca area, central Mexico and has entrusted its execution to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

The Project started in 1979 under the close collaboration with el Consejo de Recursos Minerales (CRM). The Metal Mining Agency of Japan organized a 4-geologists team and sent to the Estados Unidos Mexicanos for the first phase of the Project from September 12th to November 18th of 1979. During this period, the team, with the cooperation of the Government of Estados Unidos Mexicanos and its various agencies, was able to complete survey works on schedule for the current year.

This report hereby summarizes the survey results of the first phase and will form a portion of the all other reports related to this project.

We wish to express our heartful gratitude to the Government of Estados Unidos Mexicanos, el Consejo de Recursos Minerales and other authorities concerned, as well as to the Ministry of International Trade and Industry, the Ministry of Foreign Affairs for the cooperation and support extended to the Japanese survey team.

February, 1980

Keisuke Arita
President
Japan International Cooperation Agency

Masayuki Nishiie
President
Metal Mining Agency of Japan

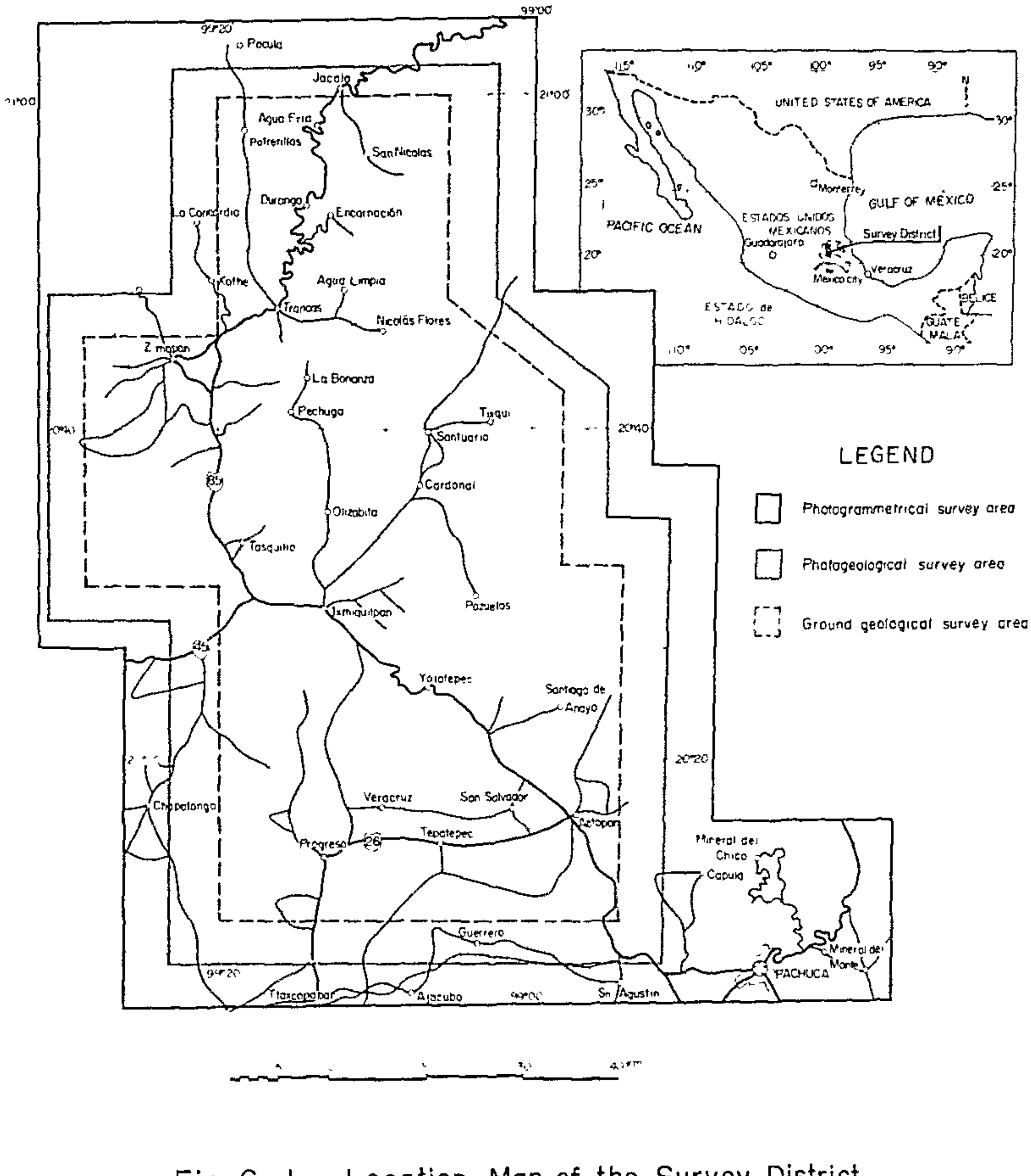

Fig G-1 Location Map of the Survey District

ABSTRACT

The second Cooperative Exploration Project between Japan-Mexico was started in fiscal 1979 as its first phase in the Pachuca district in the State of Hidalgo, central Mexico, in close collaboration among El Consejo de Recursos Minerales (CRM), Japan International Cooperation Agency (JICA), and Metal Mining Agency of Japan (MMAJ).

The survey of this year consists of the preparation of topographical maps of the whole district, photogeological interpretation, and geological survey. The actual field survey was commenced in September and continued to the end of November 1979, the result of which was compiled to this report between December 1979 and February 1980.

The result of survey was summarized as follows:

Tectonically, the survey district can be divided into two belts. Namely, one is northern, central and eastcentral parts involved in the Sierra Madre Oriental belt, and the other is westcentral and southern parts involved in the Younger Volcanic belt.

The Sierra Madre Oriental belt corresponds to a southeastern extension of the Rocky Mountain range supposed to be the front of the Alpine orogenic belt in the North American Continent.

Owing to the Nevadan orogeny during the time from lace Jurassic to early Cretaceous, geanticline in the western North American Continent had been brought into existence, and the Rocky and Mexican miogeosynclines occurred on the east side of the geanticline (ref. Fig. IV-1).

Sedimentary rocks surpassing calcareous materials in the miogeosyncline were influenced by the Laramide orogeny from the period of the latest Cretaceous, and severely folded, and finally resulted the formation of the Sierra Madre Oriental range after the continentalization.

The Younger Volcanic belt, on the other hand, is longitudinary distributed crossing the Seirra Madre Oriental belt, and there is evidence to show that the belt had been submerged by a sea connecting the Pacific Ocean and Gulf of Mexico. The belt is presumed to have been a gigantic tectonic belt, namely, an extention of a transform fault running eastwardly from the Pacific Ocean, because violent volcanic activities have continuously occurred since the time of Oligocence till now along the belt.

Reflecting the geological history of tne survey district, severely folded Cretaceous strata are distributed in the northern, central and east-central parts, and volcanic rocks are distributed in the westcentral and southern parts of the district.

The Cretaceous system distributed within the survey district is laid down conformably, from the lower, in the succession of the massive limestone formation, the black flint-alternated formation, and the shale formation. The *Hippurites* limestone formation which is assumed to be in contemporaneous heterotopic relation with the black flint-alternated formation is also distributed.

The age determination of deposition of these sediments will be carried over to the survey in the next phase as a problem to be solved by detailed

study of both macro- and nannofossils.

Among the Tertiary system, although the basal conglomerate is locally distributed, the main rocks are volcanic rocks. According to the result of K-Ar absolute age determination, the time of the effusion was 38.1±1.9 m.y. ∿ 26.5±1.3 m.y., which is considered to include most of the age of volcanic activities in the area. Therefore it is indicated that the volcanic activities of the area were culminated from the early to late stage of Oligocene.

Lithologically, lava flows and volcanic breccias of basaltic and andesitic composition predominated from the early to late Oligocene, and lava and tuff of rhyolitic composition were distributed toward the end of the later stage of Oligocene.

The geological structures of the district is characterized remarkabley by fold and faults developed within the Cretaceous formations which was disturbed during the Laramide orogeny.

In the Tertiary system, although gentle dipping of the bed and several small faults are observed, the rocks are generally stable, and any notable disturbance of the structure could not be found.

The intrusive rocks distributed in the district are granodioritic rocks, andesites and rhyolites. While andesites and rhyolites are partly distributed as small dykes, granodioritic rocks are large in size, and they are important because of their close relation to the mineralization in the district.

The K-Ar absolute age determination of the intrusion of granodioritic rocks showed the values such as 40.5±2.0 m.y. and 50.9±2.5 m.y., which correspond to the age from early to late Eocene.

At the contact between granodioritic intrusive rocks and the Cretaceous limestone, iron-copper ore deposits of pyrometasomatic type were formed, which were associated with gold and silver. In recrystallized limestone in the surrounding area of the intrusive bodies, gold and silver bearing zinc and lead ore deposits which are likely to be hydrothermal type are scattered taking the shapes of manto and chimney.

These intrusive rocks have a close relation with the mineralization, and some trends are shown in their distribution and arrangement. These are considered to be important guides to the selection of the area for future exploration.

The other notable ore deposit distributed within the district is the gold deposit in the potassium rhyolite. It is found in a part of a rhyolite lava dome which is anomalously rich in potassium. Unlike to the ordinary gold ore deposits, the deposit is not the vein type, and is entirely lacking in quartz vein and silicification. Although it seems to be weakly argillized at the working places, gold mineralization is found in the fresh rock as a whole, which led to classifying the deposit to be of a dissemination type gold deposit.

The contents of gold and silver of the samples taken at several places within the rhyolite showed quite high values compared with the primary contents of these elements found in ordinary rhyolite, which indicates

possible close relation between the activity of the rock and the mineralization of gold and silver.

It was concluded, therefore, that a systematic survey will be needed to investigate the geochemical behavior of gold, silver, and other several elements.

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CHAPTER I

INTRODUCTION

I-1 Introduction

The first Cooperative Mineral Exploration Project between Japan-Mexico was begun on the State of Coahuila, Mexico, in the 1975 fiscal year, and was completed in 1978 with many fruitful results under intimate collaboration of the both countries.

The first phase investigation of the second project has been carrying on since November 1979 in the State of Hidalgo, central part of Mexico.

The report includes the results of the investigation in this phase carried out in 1979.

The investigation in 1979 consists of three kinds of works, namely, preparation of topographic maps of the whole survery district, photogeological interpretation and geological field work, and the emphasis was put on elucidation of the general geology of the survey district. The main purpose is to make clear mutual relation between mineralization and geological phenomena, such as, stratigraphy, structure, igneous activity, etc., and to delineate promising areas of about 1,000 square kilometers for mineral exploration.

I-2 Survey Works and Examinations

Details of the investigation carried out in 1979 are tabulated in the table I-1 and I-2. Both tables respectively show the areas of each survey and the types of laboratory examination.

Table I-1 Kind of Works

Item	Area	Remarks
Preparation of topographic map	7,500 km^2	Scale 1:25,000. contour interval: 25 m
Photogeological interpretation	5,250 km^2	Photogeological map Scale; 1:100,000
Regional geological survey	3,750 km^2	Geological map Scale; 1:100,000

Table I-2 Laboratory Examinations

Type of examination		Number of samples	Remarks
Chemical analysis of ore		65	Au, Ag, Cu, Pb, Zn, 307 elements in total
Chemical analysis of igneous rock		6	Whole-rock, 13 elements each
Microscopic observations of rock thin section		177	
Microscopic observations of ore polished section		23	
X-ray powder diffraction		11	
K-Ar dating		6	
Macrofossil identification		45	
Nannofossil identification		10	
Electron probe micro-analysis	Quantitative analysis	6	
	Qualitative analysis	36	

I-3 Previous Works

Literatures described below are the principal previous reports concerning on the geology and mineral deposits in the present survey district and the surroundings.

1) Geyne, A.R. et al. (1963) Geology and mineral deposits of the Pachuca-Real del Monte district, State of Hidalgo, Mexico. C.R.N.N.R. Mem. 5E.

2) Segerstrom, K. (1962) Geology of south-central Hidalgo and north-eastern Mexico, Mexico. U.S.G.S. Bull., 1104-C, pp. 87-162.

3) Simons, F.S. and Mapes, V. E. (1957) Geología y yacimientos minerales del distrito minero de Zimapán, Hidalgo.

Literatures numbered 1 and 3 mainly describe in details on the mineral deposits located in the southeastern and northwestern parts of the survey district. Literature numbered 2 is a report on the regional geology covering an area of 6,000 km^2 extending from northwestern to southern part of the survey district. The scale of the geological map attached to the report is 1:200,000. There are some other reports concerning on the mineral deposits of the district.

These previous reports deeply contributed to the photogeological interpretation and to the planning of practical field survey.

I-4 Members

Personnel engaged in this project are as follows:

Japanese Counterparts;

1st JICA-MMAJ Mission (July 1979 ∿ August 1979)

(Conference for the program of this project)

Toshiatsu BOJYO	(Head of the Mission, JICA)
Yukio HARADA	(MMAJ, Representative of Mexico Office)
Kenji SAWADA	(MMAJ)

2nd Mission (Survey team) (September 1979 ∿ November 1979)

Motomu KIYOKAWA	(Head of the Mission, Geologist, MMAJ)
Kiyoharu NAKASHIMA	(Geologist, MMAJ)
Tetsuo SATO	(Geologist, MMAJ)
Akio ABE	(Geologist, MMAJ)

Mexican Counterparts;

(Supervision and Planning)

Guillermo P. Salas	(Director General del CRM)
José L. Lee Moreno	(Gerente, Gerencia de Estudios Especiales del CRM)
Gustavo Camacho Ortega	(Jefe, Departomento de Estudios Regionales del CRM)

(Members of the survey team)

Panfilo Sanchez Alvarado (Geologist, Departomento de Estudios Regionales del CRM)

José de Jesus Rodrigues Salinas (Geologist, Departomento de Estudios Regionales del CRM)

Marío Ernesto Vazquez Meneses	(Geologist, Departomento de Estudios Regionales del CRM)
Luis Tarcisio Arteaga Pineda	(Geologist, Departomento de Estudios Regionales del CRM)

I-5 Acknowledgements

The writers are mostly grateful to Dr. Hideo Takeda, associate geologist of CRM, dispatched from the Geological Survey of Japan by JICA, for his kind support and useful information. Also we are deeply indebted to Dr. Yukitoshi Urashima, Kagoshima University, for microscopic observation of polished ore, and Dr. Keisaku Tanaka, Geological Survey of Japan, and Dr. Hisatake Okada, Yamagata University, for their guidance on identification of macro-fossils and micro-nannofossils.

CHAPTER II

GENERAL INFORMATION

II-1 Location and Access

As shown in Fig. G-1, the survey district, covering about 5,250 square kilometers, is located in the northwest to central part of Hidalgo, east-central part of Mexico. The district extends in shape of oblong, bounded by the lines connecting the 12 coordinates written below:

1)	Northwestern limit at	N. Lat.	21°01'	and W. Long.	99°23'
2)		"	20°47'	"	99°23'
3)		"	20°47'	"	99°32'
4)		"	20°27'	"	99°32'
5)		"	20°27'	"	99°23'
6)	Southwestern limit at	"	20°07'	"	99°23'
7)	Southeastern limit at	"	20°07'	"	98°51'
8)		"	20°34'	"	98°51'
9)		"	20°34'	"	98°57'
10)		"	20°42'	"	98°57'
11)		"	20°47'	"	99°03'
12)	Northeastern limit at	"	21°01'	"	99°03'

There are two routes, both paved and all-weathered, connecting Mexico City and Ixmiquilpan situated in the center of the survey district. One is the route through the national highway No. 57 and the branch via Túla-Progreso, and the other is through the national highway No. 85 via Pachuca City. Each distance is about 160 km and able to be passed in 2 hours or so.

The national highway No. 85 runs through the survey district extending

50 km in latitude and 100 km in longitude. The highway is the only main road in the district and all the survey routes are branches of this main road.

The access in the southwestern part of the district is comparatively easy owing to the topographical features, however, the northern part and the eastern part of the highway No. 85 are rather difficult to access by car because of the steep topography of the Sierra Madre Oriental range. Owing to the difficulty of access, the survey team was obliged to settle temporal surveying bases in those regions.

II-2 Physiographic Features and Drainage Systems

Topographically, the State of Hidalgo can be divided roughly into two parts. Namely, the one, northern and eastern parts of the state, is involved in the southern part of the Sierra Madre Oriental range which traverses Mexico from NE to SE. The other is involved in the central plateau of Mexico crossing longitudinally at the middle of the country.

Accordingly, the topography of the survey district shows a feature of mountains of the Sierra Madre Oriental in northern and eastcentral parts, and another feature of the central plateau in central and southern parts.

The characteristics of the topographic feature of the mountainous part are rugged ranges of 2,600 ∿ 3,100 m in altitude and gorges having 2,000 m difference in elevation. Also those of the plateau like part are the well-dissected hilly land of 1,400 ∿ 2,400 m high, steep spurs and widely distributed plains. The principal drainage system in the

survey district is based on the Río Túla and Río Amajaque. Both rivers are the tributaries of the Río Moctezuma which is one of the biggest river in eastern Mexico.

Río Túla runs northwardly through the dissected plain of southern-central part from the vicinity of Túla located about 20 km south to the south-western corner of the survey district. The river joins main course at around the Tolimán gorge after the deviation of its direction of flowing to the northwest near Ixmiquilpan.

The main course of the Río Amajaque flows northwardly along the eastern outer side of the survey district, that is to say, she flows through the central part of the Sierra Madre Oriental just in parallel with the extending direction of the range. Accordingly, the drainage system in the eastern part of the survey district is said to be controlled by the branches of the Río Amajaque. The flowing direction of those branches is grouped into two, namely, one is in parallel with and another is at right angles to the extending direction of the Sierra Madre Oriental.

Both rivers have enough water through the year, however, most of water of the Río Túla is said to have been artificially induced from waste water thrown away in the Mexican basin in which the capital, Mexico City, is located. Reason of inducement is thought to be based on the fact that there is no river in the basin to throw waste water. Water is induced by tunnels to the Río Túla in order to drain and utilize again for agricultural use.

II-3 Climate and Vegitation

Owing to the topographic difference, climate in the district also changes in two regions. In the southern plateau, climate is mild and rather arid. Annual precipitation of about 300 mm ∿ 400 mm and annual temperature of about 19°C (maximum 39°C ±, minimum -1°C ±) are reported, and there are snowfalls rarely and ice-free except several days in a year. In the northeastern mountains, annual temperature in average is 2°C lower than the former, but annual precipitation reaches to 1,500 mm or more. More than ninety percents of the precipitation fall during the rainy season, June to October. In June and September rain falls most heavily and July and August have lesser precipitation. The difference of precipication depends upon local changes of climatic condition, such as, showers in the afternoon in June, influences of hurricane which is generated in areas of the Caribbean Sea and Gulf of Mexico.

Humidity is mostly brought from the Gulf of Mexico by winds from north or east. These winds cause heavy precipitation in area of the Sierra Madre Oriental, and to the contrary, dry up the areas of plateau and plain existing in the west and south sides of the range. These local conditions are supposed to assist and accelerate the difference of precipitation in each area.

Natural difference of vegitation can be observed in the mountains and plains owing to the difference of climate, especially difference of rainfall in each area. In arid areas located in the south, west and central parts of the survey district, where rainfall is less than 400 mm, sparse distribution of subtropical plants is quite common. Those are,

arid-region grasses, cactuses, yucca, maguey, prickly shrubs, etc. Among them maguey is the one of the important plants and is artificially cultivated in many places. In addition to those plants, thick forests of cypress are observable along Río Túla.

In the northern mountains, shrubbery of pine, oak, fir and rhododendron is grown instead of those arid type. Especially at the northeastern slope of the mountains higher than 2,600 m in altitude, beautiful forests of conifer can be seen.

As mentioned above, vegitation in the survey district involves plants of subtropical arid type and mountainous conifer type.

II-4 Industry and Agriculture

Hidalgo State is quite famous for the development of silver mines, which have been worked for long time. Among those, Pachuca-Real del Monte silver mines have been developed since sixteenth century and have been reported that the mines have produced 38,000 tons of silver and 192 tons of gold up to now. However, the mines are working in small scale only for picking of remnant ores and some prospecting at present.

The Zimapán district which is situated at the northwestern corner of the survey district, is also a mineralized area and has been developed for long time. Lead and zinc ores accompanied by gold and silver exist scatteringly as middle-class deposits in the district. Those deposits are on their way to big-scale development and they are supposed to be promising.

In addition to the mineral deposits mentioned above, there are several

small metal mines in the survey district and some of them are working at present. Also marble is being produced in some quarries.

Agriculture, the chief industry of the district, has been rapidly developed owing to the improvement of irrigation technique. Technically, agriculture is going to change its method from small-scale farming for arid area to large-scale one. Consequently, production and the kind of crops are increased and sufficiently able to serve as the supply base of Mexico City. Among agricultural products, corn, wheat, barley and beans as cereals, cabbage, lettuce, carrot, potatoes, avocado and onion, feed grains as vegitables and tomato, apple, orange, grapes, papaya, melon and watermelon as fruits are quite abundant.

Pasturage of sheep and goat is also popular among the local inhabitants of Otomi tribe, who have been living in the central part of the survey district from ancient times. Those inhabitants make a living by the cultivation of corn and making Pulque, but they are rapidly modernized by the policy of the government to spread education.

Main settlements in the survey district are Ixmiquilpan (population: about 16,000), Actopan (population: about 14,000) and Zimapán (population: about 3,000) and are located along the national highway No. 85. In addition, small settlements are scattered here and there and the population of the district is supposed to be not so sparse except the mountainous regions of north and east.

CHAPTER Ⅲ

PHOTOGEOLOGICAL INTERPRETATION

Photogeological interpretation was conducted as a link of the regional geological survey of this year, the purpose of which was to make outline of geology and geological structure of the district (5250 km^2).

The result of interpretation was compiled on the preliminary photogeological interpretation maps, 1/50,000 and 1/100,000 in scale, and they were used for regional geological survey which was consecutively carried out.

The maps were completed as a regional geological map (PL-1) and the geologic profiles (PL-2) incorporating the final interpretation based on the geological survey.

III-1 Topographical Map, Aerial Photograph and Existing Geological Map

(1) Topographical maps

Scale: 1/100,000 existing over the whole district

Scale: 1/ 50,000 drawn up this time over the whole district

(2) Aerial photographs

Scale: approximately 1/50,000 601 sheets in total

(cf. Fig. III-1, Table III-1)

(3) Existing geological data (cf. Fig. III-2)

1. Plano Geológico del Estado de Hidalgo, 1/500,000 (CRM)
2. Geologic Map and Section of the Zimapán Mining District, State of Hidalgo, Mexico, 1/25,000 (Simons, F.S. and Mapes, V. E., 1957)

3. Geologic Map and Section of South-Central Hidalgo and Northeastern Mexico, Mexico, 1/200,000 (Segerstrom K., 1962)
4. Map and Section Showing the Relation of the Pachua-Real del Monte Mining District to the Regional Geology, 1/200,000 (Geyne, A.R. et al., 1963)
5. Plano Geológico Local del Area de Encarnación Municipio de Zimapán, EDO. de HGO., 1/20,000 (Restvic Peres, I.V., 1973)

III-2 Classification Standards of Geological Units and the Results of Photogeological Interpretation

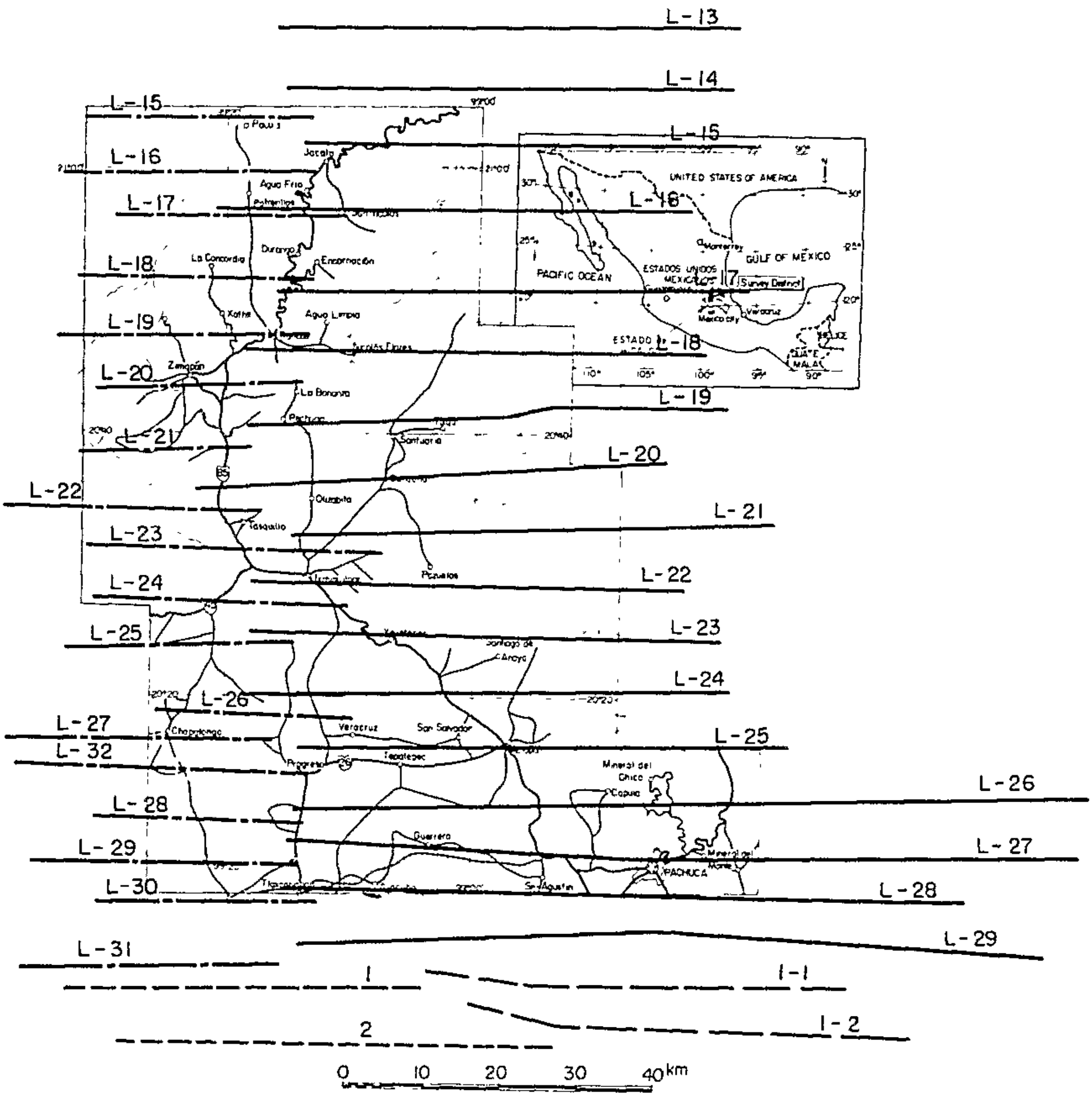
For preliminary interpretation, the elements for photointerpretation which correspond to each geological unit were determined by the correlation between photographic tone, texture, drainage pattern, etc. and geological data of the geological units which had been used in the previous works. These were applied to the whole district to classify the geological unit and to make interpretation on strike and dip of the formation, fault structure, various linear structures, and folding structure. These results of interpretation were laid down on topographical maps of 1/50,000 in scale which had been enlarged from the existing topographical maps of 1/100,000 in scale.

Taking into consideration the result of regional geological survey, the elements for interpretation were classified more in detail and were described on topographical maps of 1/50,000 in scale which had been drawn up this time, which were scaled down to compile to regional geological map of 1/100,000 in scale.

The elements used in the interpretation were classified into Cretaceous, Tertiary and Quaternary systems, and intrusive rocks, which were subdivided into geological formations and rock types as shown in Table Ⅲ-2.

These results of interpretation were comprehensively examined along with the existing data as well as various new data obtained by geological survey conducted in this year.

Fig. Ⅲ-1 Index of Flight Paths of Aerial Photograph



LEGEND

L-13	Zone 11 A
L-15	Zone 12 A
1	Zone 19 A
1-1	Zone 20 A

Table III—1 List of Aerial Photographs

(Approx. scale 1 : 50,000)

Zone	Line no.	Photo no.	Number	Zone	Line no.	Photo no.	Number
11 - A	13	7 ~ 20	14	12 - A	18	2 ~ 11	10
11 - A	14	10 ~ 23	14	12 - A	19	26 ~ 35	10
11 - A	15	7 ~ 21	15	12 - A	20	1 ~ 8	8
11 - A	16	11 ~ 27	17	12 - A	21	29 ~ 34	6
11 - A	17	3 ~ 18	16	12 - A	22	1 ~ 10	10
11 - A	18	10 ~ 25	16	12 - A	23	26 ~ 35	10
11 - A	19	8 ~ 23	16	12 - A	24	2 ~ 12	11
11 - A	20	9 ~ 24	16	12 - A	25	20 ~ 32	13
11 - A	21	6 ~ 22	17	12 - A	26	3 ~ 13	11
11 - A	22	12 ~ 33	22	12 - A	27	5 ~ 15	11
11 - A	23	10 ~ 27	18	12 - A	28	1 ~ 9	9
11 - A	24	9 ~ 26	18	12 - A	29	21 ~ 32	12
11 - A	25	2 ~ 20	19	12 - A	30	1 ~ 11	11
11 - A	26	2 ~ 29	28	12 - A	31	24 ~ 35	12
11 - A	27	4 ~ 45	42	12 - A	32	20 ~ 31	12
11 - A	28	1 ~ 25	25	19 - A	1	1 ~ 17	17
11 - A	29	4 - 37	34	19 - A	2	18 ~ 37	20
12 - A	15	28 ~ 35	8	20 - A	1	4 ~ 18	15
12 - A	16	1 ~ 10	10	20 - A	2	22 ~ 39	18
12 - A	17	31 ~ 40	10			Total	601

Fig III-2 Index Map of Previous Work Areas

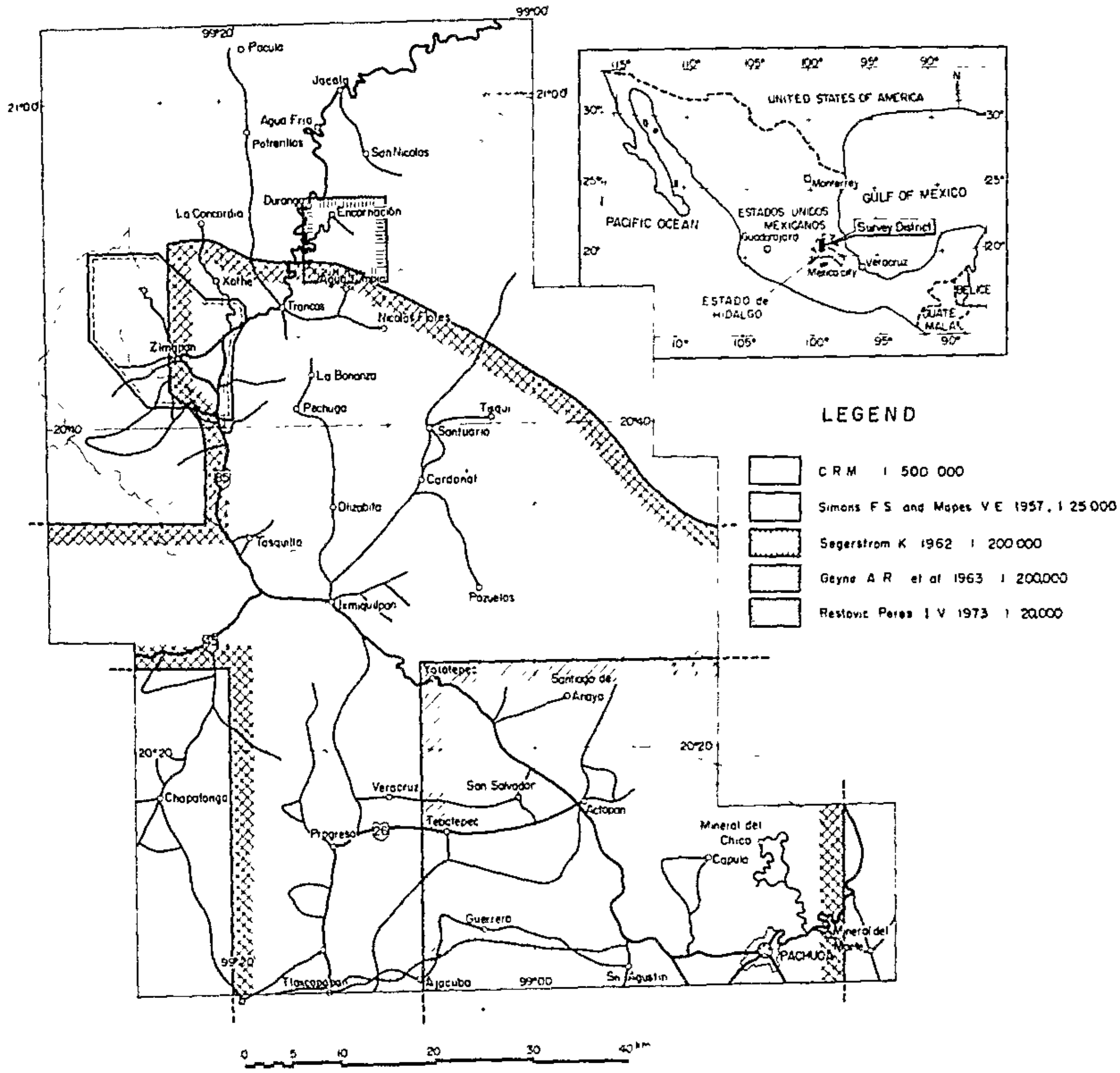
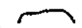
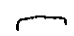


Table III-2 Classification Standard of Geological Unit by the Photogeological Interpretation

	Geological unit	Photographic		Drainage		Resistivity	Topography			Banding pattern of stratification	Lithofacies confirmed by field checking
		Tone	Texture	Pattern	Density		Form	Section			
								Valley	Ridge		
Tertiary-Quaternary System	Tcgs	white grey to grey	granular	dendritic	dense	low	flat			nil	gravel, sand, silt and ash
	Tba3	grey	smooth	dendritic	rough	high	flat			nil	basalt lava
	Trhy2 (West of Santuario)	dark grey	granular partly rugged	dendritic	dense	low to moderate	steep			nil	rhyolite lava dome
	Trhy2	white grey to grey	granular, partly rugged	dendritic	rough	moderate	somewhat rounded			nil	rhyolite lava
	Tan3	grey to dark grey	coarse and rugged	dendritic	moderate	moderate	intermediate			nil	andesite
	Tt2	white grey, grey and dark grey	granular to coarse	dendritic	moderate	low	somewhat rounded			distinct	tuff, lapilli tuff, tuff breccia, tuffaceous sandstone and conglomerate
	Tan2 Tan1	grey to dark grey	granular	dendritic	moderate to dense	moderate and high	somewhat rounded partly steep			nil	andesite lava and pyroclastic rock
	Tba2 Tba1	grey, partly white grey	fine to granular	dendritic	moderate	low and moderate	somewhat rounded partly steep			nil	basalt lava and pyroclastic rock
	Tcg	grey	granular	dendritic	moderate	low	rounded			indistinct	conglomerate
Cretaceous System	Ksh3 (Bca.del Encino area)	white to grey	fine to granular	parallel partly dendritic	dense	low	somewhat rounded			indistinct partly distinct	shale
	Ksh3 (Zimapan area)	white grey to grey	granular	parallel and dendritic	moderate to dense	low	somewhat rounded or intermediate			indistinct	siltstone, sandstone and shale
	Ksh3 (Las Trancas -Santuario area)	white grey to grey	fine to granular	parallel partly trellis	dense	low to moderate	steep, partly intermediate			indistinct partly distinct	shale intercalated with calcareous shale, siltstone and sandstone
	Kls2	white grey to grey	granular	parallel	rough to moderate	high to moderate	somewhat rounded			distinct partly indistinct	massive limestone
	Klf	grey and dark grey	granular	parallel to dendritic	moderate	moderate	intermediate partly steep			distinct partly indistinct	alternation of limestone marl, calcarenite, shale and flint
	Ksh2	light grey to grey	fine to granular	parallel	dense	low	steep partly intermediate			indistinct	shale intercalated with calcareous shale, siltstone and sandstone
	Kls1	grey to dark grey	granular to coarse	parallel dendritic	rough or moderate	high or moderate	rounded or gentle			indistinct, partly distinct	massive limestone
Intru-sive rock	Tigd	white grey to grey	granular	dendritic	dense	low to moderate	steep			nil	quartz diorite, granodiorite and diorite

CHAPTER Ⅳ GEOLOGY

IV-1 Outline of Geology

Tectonically, the survey district can be divided into two belts. Namely, one is northern, central and eastcentral parts involved in the Sierra Madre Oriental belt, and the other is westcentral and southern parts involved in the Younger Volcanic belt.

The Sierra Madre Oriental belt corresponds to a southeastern extension of the Rocky Mountain range supposed to be the eastern front of the Alpine orogenic belt in the North American Continent.

Owing to the Nevadan orogeny during the time from late Jurassic to early Cretaceous, geanticline in the western North American Continent had been brought into existence, and the Mexican miogeosyncline occurred on the east side of the geanticline (ref. Fig. IV-1).

Sedimentary rocks surpassing calcareous materials in the miogeosyncline were influenced by the Laramide orogeny from the period of the latest Cretaceous, and severely folded, and finally resulted the formation of the Sierra Madre Oriental range after the continentalization.

The Younger Volcanic belt, on the other hand, is longitudinary distributed crossing the Seirra Madre Oriental belt, and is presumed to have been a gigantic tectonic belt, namely, and extention of a transform fault running eastwardly from the Pacific Ocean, because violent volcanic activities have continuously occurred since the time of Oligocene till now along the belt.

Reflecting the geological history of the survey district, severely folded

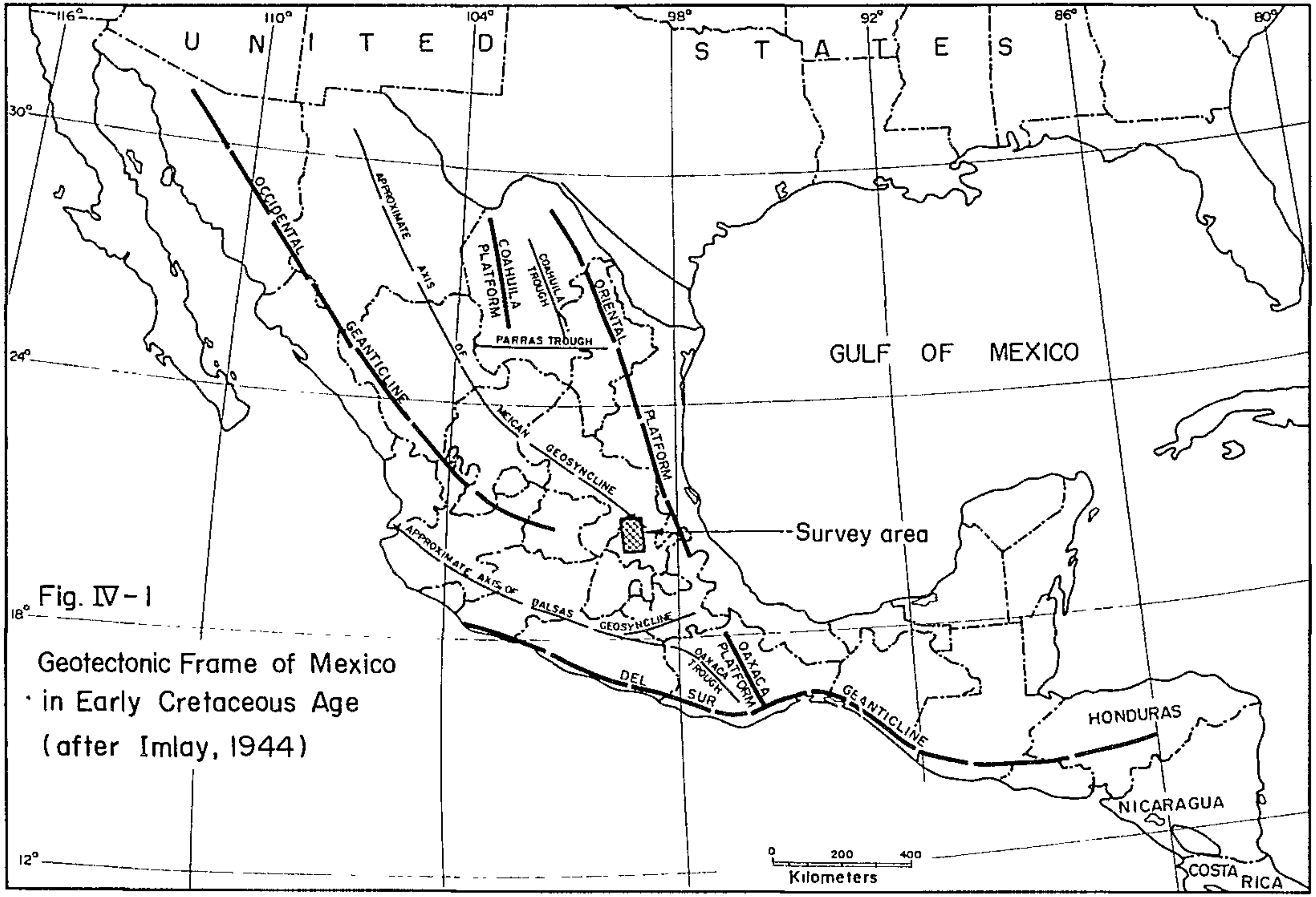


Fig. IV-1

Geotectonic Frame of Mexico in Early Cretaceous Age (after Imlay, 1944)

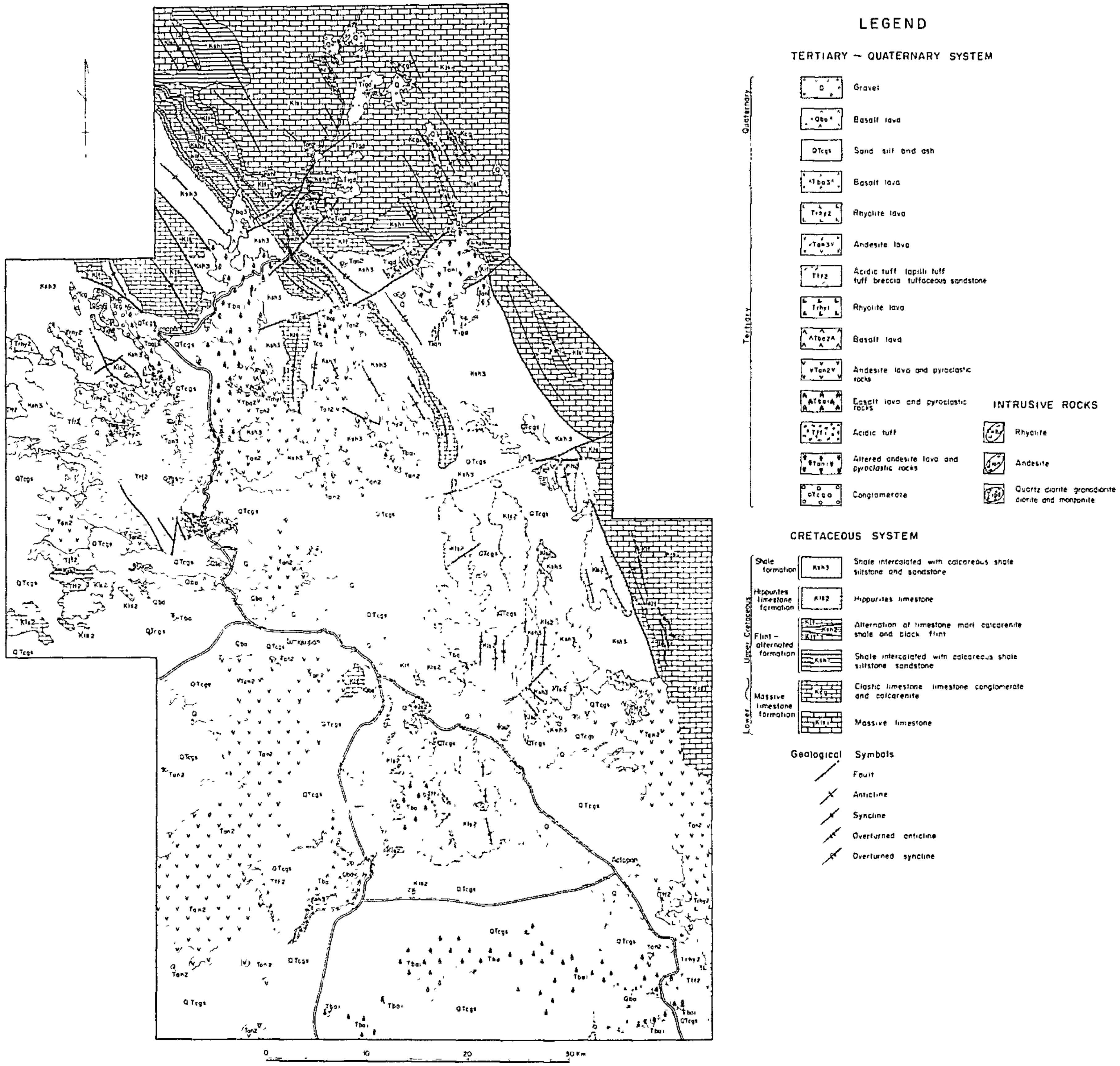
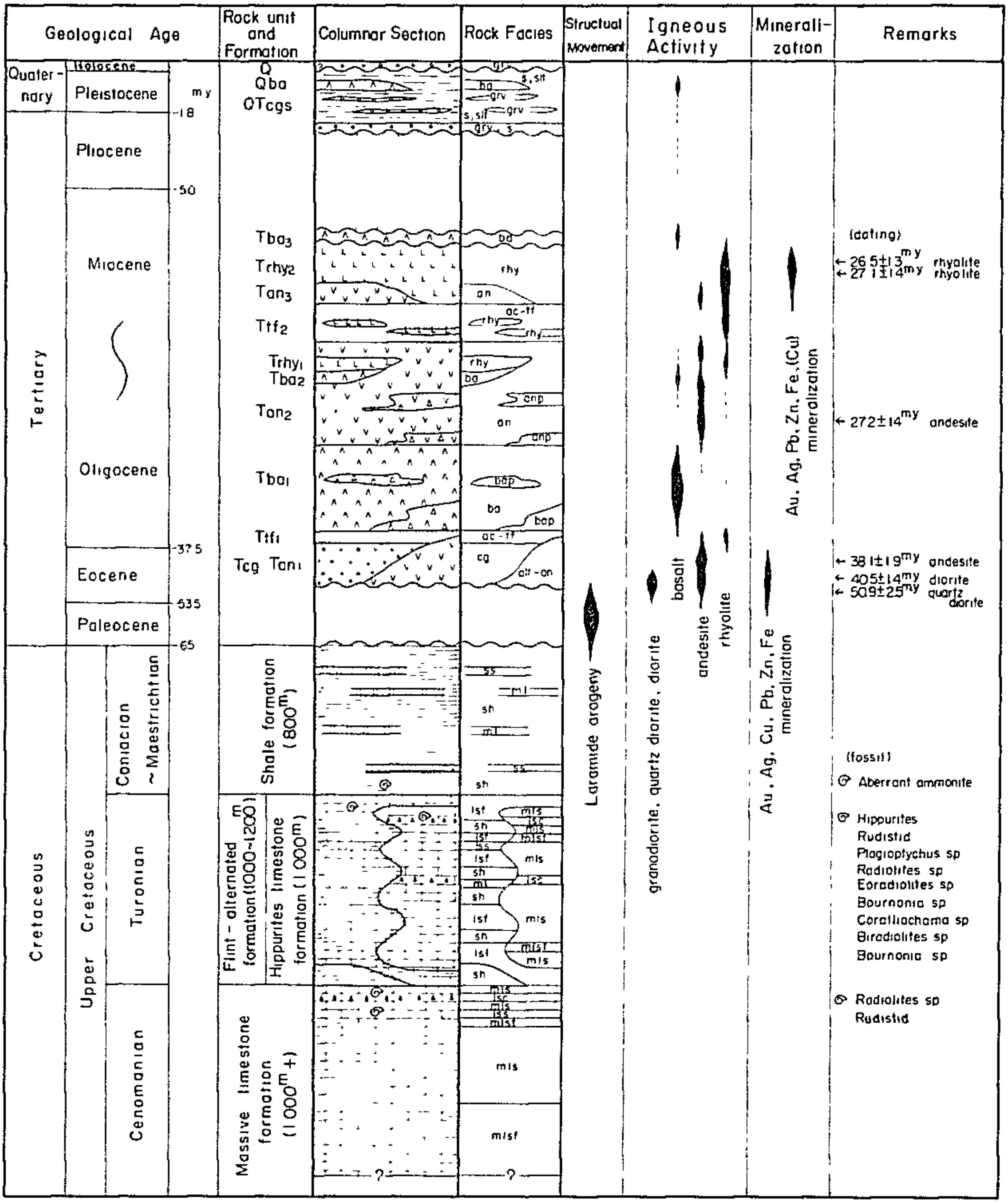


Fig. Ⅳ-2 Geological Map of the Survey District

Fig IV-3 Generalized Stratigraphic Column of the Survey District



Abbreviations

misf	massive limestone with lenticular black flint	alt-an	altered andesite
mls	massive limestone	ba	basalt
lss	calcarenite	bap	basaltic pyroclastic rocks
lsc	clastic limestone, limestone conglomerate	an	andesite
sh	alternation of shale and calcareous shale	anp	andesitic pyroclastic rocks
lsf	thin to medium bedded limestone with black flint	rhy	rhyolite
ml	marl	grv	gravel
ss	sandstone	s	sand
cg	conglomerate	slt	silt
ac-tf	acidic tuff, tuff breccia	ⓕ	fossil

Fig. IV-4 Schematic Stratigraphic Column of the Whole Area

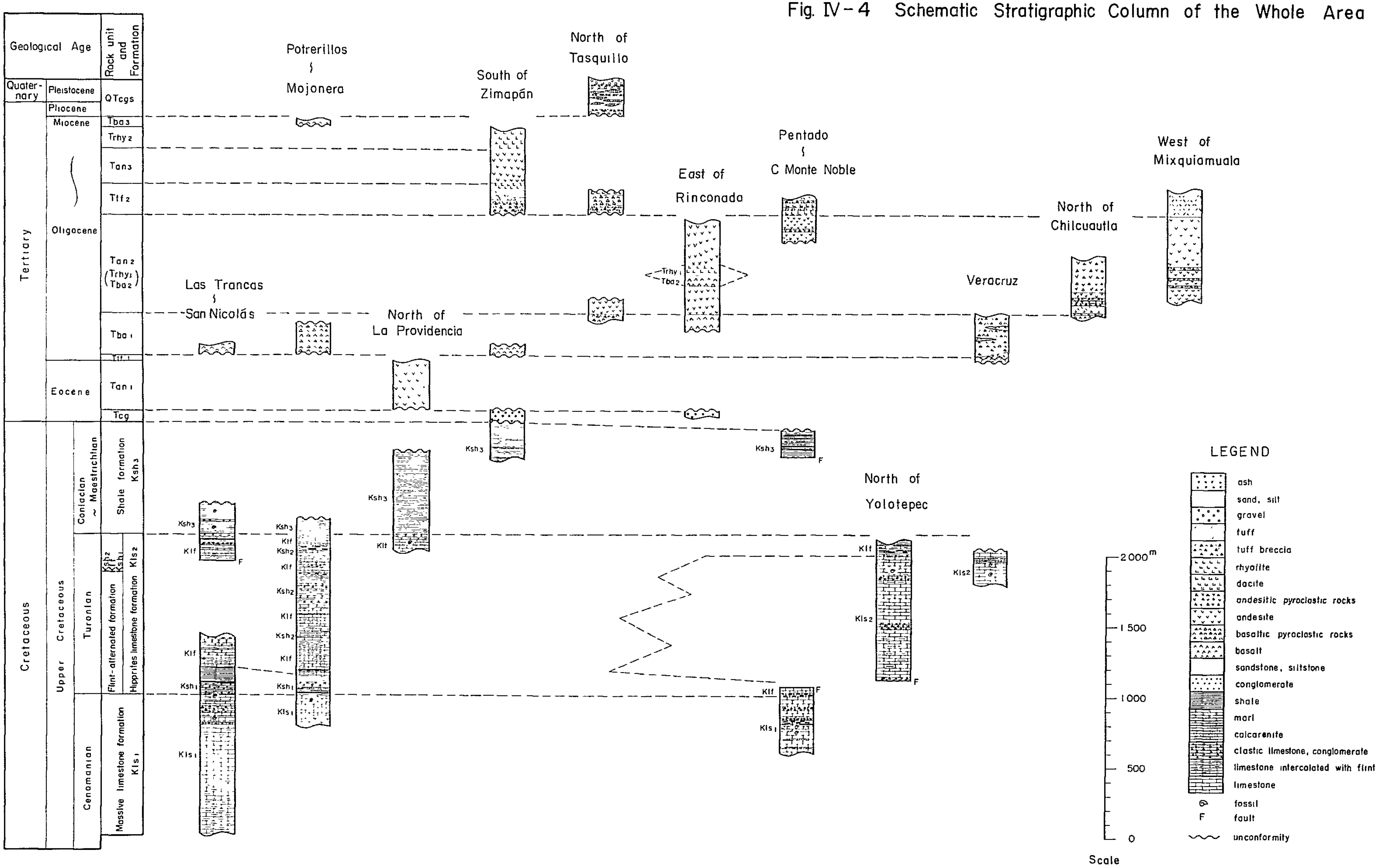


Table IV-1 Stratigraphic Correlation of Geological Units in the Sierra Madre Oriental, Central Mexico

System	Series, and Stage	Southeastern San Luis Potosí (Imlay, 1944 B 1952)	Huasteca area (Eastern Hidalgo and Northern Veracruz) (Imlay, 1944 B 1952)	Eastern Querétaro, Western Hidalgo, and Northern México (Imlay, 1944 B 1952)	Huayacocotla anticlinorium area (Carrillo Bravo, 1965)	Encarnación area, Hidalgo (Restovic Perez, 1973)	Zimapán area, Hidalgo (Simons & Mapes, 1957)	South-Central Hidalgo and Northwestern México (Segerstrom, 1962)	Bonanza-Pechuga area, Hidalgo (Chaires Blanco, 1978)	Cardonal area, Hidalgo (Casarrubias Jinenes, 1973)	Pachuca-Zimapán area, Hidalgo (JICA & MMAJ, 1980)	Pachuca-Real del Monte area, Hidalgo Geyne et al., 1963	Central and Northern México (Fries, 1956)
Quaternary	Holocene					Alluvium	Alluvium, Terrace deposits	Clastic deposits, caliche, and basalt	Alluvium	Alluvium	Q Qba	Alluvium basalt and Guajolote trachyte	Chichinautzin basalt series
	Pleistocene						Zimapan fanglomerate; Daxi fanglomerate				QTcgs		
Neogene	Pliocene				Volcanic rocks (basalt and rhyolite)			Tarango and Atotonilco El Grande fms; San Juan group; Jalpan andesite; Don Guiyo tuffs Zumate and Tezuantla fms	Intrusive rocks (quartz diorite latite porphyry)	Tarango fm; Don Guinyo tuff		San Cristobal fm; Tarango and Atotonilco El Grande fms; Navajas rhyolite; Zumate fm	Cuernavaca fm
	Miocene					Intrusive rock (granodiorite)	Las Espinas volcanic rocks	Pachuca group	Extrusive rocks and tuff (andesitic rhyolitic)	Viscaina fm; Rhyolitic porphyry	Tba3	Tezuantla fm; Cerezo fm; Viscaina fm; Santa Gertrudis fm; Real del Monte fm	Zempozta andesite series and Tepozllan fm
Paleogene	Oligocene					Extrusive rock (trachyandesite)	El Morro fanglomerate	El Morro fanglomerate			Trhy2; Tan2; Tba2; Tba1; Tff1	Pachuca fm; Corteza fm; Santiago fm	Tilzapotla rhyolite series
	Eocene									El Morro fm	Tcg; Tan1	El Morro group	Balsas clastic group
	Paleocene												
Upper Cretaceous	Maestrichtian	Cárdenas fm	Méndez shale										
	Campanian	Méndez shale		Not identified			Thin alternation of gray calcareous shale and grayish white limestone	Mexcala fm; Méndez fm			Kshs	Méndez fm; Mexcala fm	Mexcala fm
	Santonian		San Felipe fm										
	Coniacian	Tamaposo limestone											
	Turonian	Agua Nueva fm	Agua Nueva fm	Limestone, thick-bedded, contains many rudistids	Not identified	Soyatal fm		Soyatal fm	Soyatal fm	Soyatal fm	Klf; Kpn2; Ksh1; Kls2	Soyatla fm; Cuautla fm	Cuautla fm
	Cenomanian										Kcg; Kls1		
Lower Cretaceous	Albian		Tamaulipas limestone	Limestone; Rudistid limestone		El Doctor fm; Tamaulipas fm	Gray thin-bedded limestone intercalating calcareous sandy shale and chert nodule or lens	El Doctor limestone	El Doctor fm	El Abra fm; Cuesta del Cura fm		El Doctor fm	Morelos fm
	Aptian	Not identified	Limestone marl, and shale; Limestone, compact		Otates beds								Xochicalco fm
	Neocomian: Barremian			Not identified						Lower Tamaulipas fm			
	Neocomian: Hauterivian				Lower Tamaulipas fm								
	Neocomian: Valanginian		Marl and shale		Upper Pimienta fm			Santuario fm	Santuario fm				
	Neocomian: Barriasian									Santuario fm			
Upper Jurassic	Portlandian	Pimienta fm	Pimienta fm		Lower Pimienta fm		Thin alternation of dark gray shale and limestone intercalating black limestone	Las Trancas fm	Las Trancas fm				
	Kimmeridgian	Tamán fm	Tamán fm										
	Oxfordian	Not exposed	Huizachal F		Tamán fm								
	Callovian		Dark limestone										

Cretaceous strata are distributed in the northern, central and east-central parts, and volcanic rocks are distributed in the westcentral and southern parts of the district.

Intrusive rocks, in general, show the shape of small, irregular stock and are scatteringly distributed in the northern part. Ore deposits are concentrated around the intrusives, and are iron-copper ore deposits of pyrometasomatic type and lead-zinc ore deposits of hydrothermal type.

In general, the ore deposits show irregular-massive, chimney or manto shapes. Gold and silver are associated characteristically with those ore more or less. In addition, there is a gold mine in the potash rhyolite.

As mentioned above, the survey district is situated in a highly interesting place on the metallogenetic point of view.

Principal purpose of this phase survey is elucidation of regional geology of the district and delineation of promising zone for mineral exploration in the next phase.

The present report describes only important points of the main aims expecting a minute report on the continuous detailed survey in the next phase.

IV-2 Stratigraphy

The rocks distributed in the survey district are Cretaceous and Tertiary systems, intrusive rocks which penetrate these systems, and Quaternary system which filled up topographical low lands in the central and the

southern part of the survey district (cf. Fig. IV-2). The exposure of the basement rocks of these formations could not be found in the district.

IV-2-1 Cretaceous System

In terms of Jurassic and Cretaceous systems in the central part of Mexico including the survey district, several research and investigation were conducted previously, in which nomenclature and correlation of rock facies, fossil, and formation had been made (Imlay, 1944; Segerstrom, 1962).

The geological data which were obtained in the survey of this time, however, raised some questions against the result of the past surveys (cf. Table IV-1). These questions are to be solved by the detailed survey in the next fiscal year. Therefore, in order to avoid confusion, the name of Cretaceous sedimentary rocks was temporally given in this report based on rock facies and fossils of corresponding rocks without using the names given in the past reports.

(1) Massive limestone formation

This is the oldest formation among the rocks distributed in the survey district, which was divided into two facies of Klsl and Kcg. Among them, Klsl is the main component, while Kcg is partly intercalated in the upper part of the formation.

Distribution The formation is mainly exposed in the northern part of the district and is also distributed in small scale in the eastern periphery of the central part. In concrete terms, good

exposures can be observed along the cuttings of the national highway No. 85 from the point about 235 km from the starting point in Mexico City (about 18 km northeast of Zimapán) to the northern boundary of the survey district, and on the cliffs in the neighboring area.

In this part, the national highway No. 85 runs approximately in northeast direction intersecting the formation at right angle with the general strike of it. Therefore, the formation is exposed in great amount across the highway to both directions of northwest and southeast which coincide with the elongation of the Sierra Madre Oriental range.

Another exposure of the formation can be found to the northeast of the point which is 10 km northeast of Santiago de Anaya at the eastern periphery of central part of the survey district.

Thickness Accurate thickness of the formation can not be measured because its base has not been confirmed yet. The thickness, however, more than 1,000 m was confirmed from the upper boundary to the lower-most part of the exposure. It is apparently divided into three parts, such as lower part (400 m), middle part (300 m), and upper part (300 m).

Rock facies The formation mainly consists of cliff-forming, thick-bedded, massive, fine-grained, gray to grayish brown limestone (Klsl) partly associated with intercalating thin beds of (Kcg) such as clastic limestone, limestone conglomerate, and calcareous sand-stone.

The lower part (400 m) consists of gray (partly dark gray and grayish brown), fine-grained and medium- to thick-bedded (20 ∿ 60 cm in general, 1 m in maximum thickness) limestone.

It is a characteristic of this part that nodular or lenticular black flint is commonly contained though small in amount.

The exposure of the lower part can be found at the bottom of deeply incised creeks along the axes of both anticlines of San Francisco and Durango.

The middle part mainly consists of relatively homogeneous, gray in color, fine-grained, compact, thick-bedded, massive limestone. It is, however, at the lower part, intercalated with medium-bedded limestone and dense fossil zones. The exposure of these beds is found in the creeks along anticlinal parts such as San Francisco and Durango.

The upper part mainly consists of grayish white to grayish brown (partly dark grayish), thick-bedded limestone, partly intercalated with limestone conglomerate, calcareous sandstone, and marl (Kcg). It is fossiliferous in general characterized by intercalation of dense fossil zones of foraminifera and macrofossils. Accordingly, this part is heterogeneous compared with the lower and middle parts.

Although the upper part is found almost parallel with the upper sequences, it is repeatedly distributed from Agua Fría village to San Nicolás village in the northeastern part of the district because the massive limestone formation has a repetition of gentle anticline

and syncline compared with other formations overlying it.

Fossil and correlation   Fossils shown in the following table were sampled from this formation during the survey of this time.

Table IV-2 Fossils from the Massive Limestone Formation

Actaeonella sp.

Bivalvia

Foraminifera

Gastropod

Nerinea sp.

Radiolites sp.

Rudistes

Although age determination can not exactly be made only from these fossils, the formation can be correlated to the El Doctor Limestone (Wilson and others, 1955) which is considered to be of the Albian to Cenomanian stages taking into account the matters, such as

(1) the kind of fossils contained,

(2) thick limestone formation, and

(3) that *Radiolites* is the fossil which occurs in the strata of Cenomanian and more younger stages.

(2) The flint-alternated formation

The formation consists of the lower part (Ksh1) rich in marly rocks and the upper part (Klf, Ksh2) composed of alternation of calcareous rocks (Klf) and marly rocks (Ksh2) intercalating black flint.

(2)-1 The lower part (Kshl)

Distribution It is distributed around Potrerillos village at the northwestern periphery of the district, in the area from Dos de El Aguila mine to the southeast, and in the east-central part of the district, overlying conformably the massive limestone formation of the lower sequence.

Thickness It is measured to be 150 m in thickness in the vicinity of Potrerillos village mentioned above, 200 m at El Zapote, and 180 m at Arroyo Cuesta Colorada which is on the southeast of El Zapote. It is entirely missing in further southeastern part, to the northeast of Santiago de Anaya village. It is divided, lithologically, into the lower part (10 $\sim$ 20 m), middle part (150 m $\pm$), and the upper part (30 m).

Rock facies The lower part consists of alternation of dark gray, thin- to medium-bedded calcareous shale and lenticular limestone. The middle part mainly consists of grayish brown, thin-bedded shale partly intercalating medium-bedded graywacke and calcareous shale. The upper part consists of dark gray, medium-bedded calcareous shale, which transitionally changes to the upper member.

Relation with the lower formation The relation with the lower massive limestone formation is apparently conformable and covers it in low angle in general as observed along the national highway No. 85 between Dos de El Aguila and El

Zapote. In that part, the national highway No. 85 makes the geological boundary, where the formation is distributed in the topographically upper part from the highway, and the massive limestone occupies the position lower than the highway. However, it is estimated that an unconformity may exist between this formation and the lower formation (Klsl) because of the variation of thickness of the beds and missing of this formation in the eastcentral part of the district. It transitionally changes to the upper sequence.

(2)-2 The upper part (Klf, Ksh2)

Distribution The formation is extensively distributed in the northern half of the survey district, and only a little is found in the southern half. The exposures are found in long and narrow zones from the northwestern to the north-central parts of the district.

In concrete terms, the main part of the formation can be observed in such places as along the road branched off from Puerto de Estancia located along the national highway No. 85 to the north toward San Francisco (at the point 10 km north from the junction and the northward), along the highway (the section between the point about three kilometers north of Puerto de Las Trancas village and Maguey Verde village), and along a trail to Agua Limpia village branched off from the road at Puerto de Las Trancas village toward Nicolás Flores.

Thickness The formation is generally intensely folded, in which steeply dipped minor folding structures are observed in every place. Furthermore, since it mainly consists of alternation of calcareous rocks and lutaceous rocks, and no key bed nor graded bedding in sandstone could be found, accurate measuring of the thickness of formation was quite difficult. However, around Mojonera village, the succession of sedimentary cycles of the major four units from the calcareous facies with intercalation of thin beds of black flint to the lutaceous facies, is normal, and reversed structure in large-scale has not been found, although a lot of minor folding can be observed. Therefore, it is considered that the formation apparently assumes to have a great thickness because of the development of intraformational folding.

As the result, synthetic judgement on the thickness of the beds led to the conclusion that the thickness of the formation would be about 1,000 m.

Rock facies The formation has a rock facies which shows a sedimentary cycle of the four units overlapping each other from lower to upper.

The first unit has a thickness of about 350 m, the lower part of which mainly consists of dark gray, medium-bedded limestone intercalated with thin-bedded shale and black flint. It changes in the upper part to an alternation of dark gray, medium- to thin-bedded limestone and shale.

The second unit has a thickness of about 370 m. About 100 m of the lower part mainly consists of gray to dark gray, medium-bedded limestone intercalated with thin beds of black flint and shale. The rocks of its upper part consist mainly of gray, medium-bedded limestone with comparatively scarce intercalation of other beds. In the upper 220 m, on the contrary, the alternation of thin-bedded marl, shale and siltstone overlaps each other.

The third unit has a thickness of 205 m. The lower 100 m mainly consists of an alternation of dark gray marl, calcareous sandstone and shale intercalated with black flint. The upper sequence of it comprises medium-bedded limestone, 30 m in thickness.

The upper part, 75 m in thickness, consists of alternation of grayish brown, thin-bedded marl and calcareous shale intercalating thin beds of black flint.

The fourth unit mainly consists of dark gray, medium-bedded limestone intercalating thin beds of black flint. The thickness is about 75 m.

As described above, the rocks of this formation have a rock facies showing sedimentary cycle of four units, and also shows a tendency of increasing terrestrial clastics in the sediments as going from the first unit to the upper sequence.

Fossil The fossils in this formation is quite unevenly distributed and is scanty of fossil in general.

Following fossils were sampled at the vicinity of Yonthe mine and on the north of Santuario village during the survey of this time.

Table IV-3 Fossils from the Flint-alternated Formation

Macrofossils

Bacultidae gen. et sp. indet. (abundant)

coiled ammonite (evolute form)

" " (involte form)

Diplomoceratidae gen. et sp. indet.

Eoradiolites sp.

Gastropod

Nerinea sp.

Nannoplankton

Eiffellithus turriseiffeli

Parhabdolithus angustus

Parhabdolithus embergeri

Watznaueria barnsae

The combination of these fossils shows that the age of sedimentation of the formation were from Cenomanian to Turonian.

(3) *Hippurites* limestone formation (Kls2)

The formation comprises thick-bedded, massive reef limestone characterized by the rich occurrence of *Hippurites*. As mentioned below, this formation and the one intercalating black flint are in the relation of interfinger.

<u>Distribution</u> Distribution of the formation is limited to the southern half and one place in the western part of the district.

The area of main distribution in the southern half makes a zone extending from eastern central part to southern central part with east-west width of about 15 km and north-south extention of about 40 km, where independent mountain masses are arranged in the north-south direction.

Another minor locality is found only in the vicinity of San Lucas at the western periphery of the central part.

<u>Thickness</u> The thickness of the formation is measured to be about 1,000 m.

<u>Rock facies</u> The formation mainly comprises gray to grayish brown, thick-bedded, massive, fossiliferous limestone, partly consisting of reef limestone characterized by *Hippurites* in the upper part. Some heterogeneous clastic limestone and brown flint are intercalated partly.

The lowest part, 450 m in thickness, is gray, thick-bedded, fine-grained and compact limestone partly intercalating the nodule of

brown flint. The upper 50 m sequence consists of heterogeneous limestone conglomerate.

The middle part, 300 m in thickness, comprises grayish brown, fine-grained, compact and massive limestone partly intercalating dark gray, medium-bedded limestone.

The upper part, 200 m in thickness, consists of grayish brown, coarse-grained, heterogeneous reef limestone, containing Rudistes such as *Hippurites*.

Fossil The following fossils were sampled from the formation during the survey of this time.

Table IV-4 Fossils from the *Hippurites* Limestone Formation

Central part of the district

Biradiolites sp.

Bournonia sp.

Coral

Coralliochama sp.

Eoradiolites sp.

Gastropods

Hippurites sp.

Nerinea sp.

Radiolites sp.

Hippuritacea

South - central part

Gastropods

Nerinea sp.

Plagioptychus sp.

Hippuritacea

Southern most part

Bivalvia

Bournonia sp.

Hippurites sp.

Requienia sp.

West - central part

Caprinidae gen. et sp. indet.

Echinoidea

Monopleuridae gen. et sp. indet.

Nerinea sp.

Hippuritacea

The combination of these fossils indicates that the upper part of this formation was laid down in Turonian stage in the reef environment.

Relation with the lower sequence   In contrast to good exposure of other Cretaceous sedimentary rocks in northern half of the district, the distribution of the formation is limited to southern half of the district. Therefore the stratigraphical relation between this formation and other Cretaceous rocks can be observed only at two places as shown in the following.

(1) In the vicinity of San Lucas

The formation covers conformably Kshl shale.

(2) A hill to the north of Xuchitlan, southcentral part of the district.

The formation is conformably covered by Klf flint-alternated formation. The relation observed in these two places indicates that the formation is a member of the flint-alternated formation. On the other hand, the result of fossil determination indicates that the age of the flint-alternated formation is of from Cenomanian to Turonian stages, though not decisive because of insufficient fossil samples obtained from this formation. It is confirmed that the upper part of the formation belongs to the Turonian stage. Therefore, the time of these sedimentation is considered to be almost contemporaneous, and moreover, the stratigraphical relation of these two formations shows nothing contradictory to it. The rock facies, however, is quite different. While this formation indicates the environment of neritic reef sedimentation, the flint-alternated formation is intercalated with black flint, which indicates the more abyssal sedimentary environment with predominant calcareous rocks, and the area of distribution is separated in the northern and southern halves.

From these facts, it is considered that the flint-alternated formation (klf, Ksh2) and *Hippurites* limestone formation (Kls2) are contemporaneous heterotopic facies and that they are partly in the relation of interfinger. Imlay (1944) pointed out that the phenomena which had often occurred in such neritic sedimentary environment could be observed throughout the whole region of the Mexican geosyncline.

The relation between the formation and the massive limestone formation of the lower sequence has not been confirmed yet.

The correlation with the past survey data shows that the *Hippurites* limestone formation is consistent with the Cuautla Formation on rock facies, fossil and stage (Fries, 1956). However, it will be a problem to be solved in the future that the rock facies and thickness of the flint-alternated formation does not correspond well to those of the Soyatal Formation (Wilson, 1955; The Soyatal Formation does not intercalate black flint) which is in the relation of contemporaneous heterotopic facies with the Cuautla Formation.

(4) Shale formation (Ksh3)

This is the upper-most formation among the Cretaceous rocks distributed in the district, and mainly consists of phyllitic shale.

Distribution The main distribution of the formation is observed in the northern half of the district. It is also partly distributed in the eastcentral part.

In concrete terms, large-scale exposures are found in a number of places as mentioned in the following.

(a) The vicinity of San Miguel, San Antonio, and Bothino (to the west of Zimapán)

(b) An area to the northwest of Puerto de las Trancas, a town along the national highway No. 85.

(c) The neighboring area of Santuario, in the central part.

(d) The vicinity of Pechuga and Bonanza, to the northwest of Santuario.

(e) The neighborhood of Tixqui, Poterero, and Nicolás Flores, in the eastern central part.

(f) An area to the northeast of Santiago de Anaya. It is a partial exposure which corresponds to the southeastern extention of the main exposures mentioned above.

Thickness The uppermost part of the formation is covered by the Tertiary system in the relation of angular unconformity. Since the formation mainly consists of thin bedded shale, it seems to be more plastic than others, resulting in the presence of intense minor folding structure in every place. The maximum thickness of the formation was measured to be 800 m on geological profile.

Rock facies It has homogeneous rock facies in general, although some change was observed among the areas of exposure as well as the sequences from lower to upper.

The lower part of the formation exposed in the mountainous area to the east of Rinconada village which is along the national highway No. 85, mainly consists of grayish brown, thin-bedded shale intercalated with brown, medium-bedded marl.

Other exposures which are considered to be those of the middle to upper parts are as follows:

(1) In the vicinity of Pechuga and Bonanza, it mainly consists of brown to medium-bedded shale intercalating thin-bedded greenish gray graywacke and dark gray marl.

(2) In the vicinity of Poterero to the north of Santuario, it consists of alternation of dark gray, medium- to thin-bedded calcareous shale and brown, thin-bedded shale.

(3) To the west of Zimapán in the western central part, it consists of alternation of grayish brown phyllitic siltstone, sandstone, and shale with minor intercalation of medium-bedded marl.

From the above, it can be said that the rocks of the middle and upper parts are more sandy in the western part than those in the eastern part.

Fossil The formation is poor in fossil occurrence, and it is not preserved well possibly because of intense folding.

The following fossils were sampled at several localities described below during the survey.

(1) In the vicinity of the junction of the branch road to Nicolás Flores from Puerto de Las Trancas which is along the national highway No. 85, and at the point about 500 m north of the junction along the highway.

aberrant ammonite

Rudistid (aff. Caprinidae?)

(2) At the point along the road one kilometer north of Santuario.

Coral

Bivalvia

The stage can not be determined only from these fossils.

(3) At the point along the road toward Tonaltongo which is 10 km to the east of Yonthe.

Nannoplankton

Broinsonia enormis

Cribrosphaerella ehrenbergii

Cretarhabdus conicus

Eiffellithus eximus

Micula staurophora

Watznaueria barnsae

Watznaueria aff. *W. communis?*

From the combination of these fossils, the age of the formation is considered to be from late Turonian to late Campanian. However, since the position of the fossils sampled were stratigraphically in the lower-most part of the formation, it is possible that the upper part of the formation may have been extended to Maestrichtian stage.

Relation with the lower formation This formation conformably contacts with the lower sequence.

Correlation It is correlated to the Méndez Formation from the stratigraphical position and the rock facies.

IV-2-2 Tertiary System

The Teritary system in the survey district is mostly composed of volcanic rocks except the basal conglomerate. The system is widely distributed forming separated gigantic mountain ranges, namely, the Actopan range of southeast, the Xinthe range of southwest, the longitudinal range in southernmost and the Juarez range of the central and western areas. In addition, there are several isolated mountains on a small scale in the area. Roughly speaking, the distributed areas of these volcanic rocks occupies the northeastern margin of the Younger Volcanic belt suggesting that the igneous activity which brought out the Tertiary volcanic rocks within the area, belongs to a part of the wider activity of the Younger Volcanic belt.

Volcanic succession of the rocks is not clearly confirmed because of the separated distribution of each rock unit. The volcanic rocks in the area, however, are considered to have been generated by the activities having intimate relation with each other. Here, the volcanic rocks are classified into twelve kinds due to the lithologic characters and their absolute ages determined by the K-Ar method.

(1) Conglomerate (Tcg)

Distribution The widest distribution of the rock is observable in the neighbourhood of El Barron - El Alamo - San Miguel to the west of Zimapán in a shape of crescent along the foothills. Rather narrow exposures are observed near the top of hills from La Majada to El Mezquite. Besides, narrow exposures can be seen along the

bottom of the marsh, southeast of Rinconada on the national highway No. 85.

Lithologic characters Mostly comprises angular to sub-angular pebbles derived from Cretaceous limestone, and generally involves andesitic volcanic pebbles in a small quantity. Diameters of pebbles are mostly 20 ∿ 30 cm and also extend from smaller (less than 1 cm) to bigger (more than 100 cm) ones. Pebbles are cemented in matrix of reddish brown, oxidized silty materials. Sorting of pebbles is unable to observe, but calcareous pebbles of flat ellipsoid in shape are accumulated in parallel with each other and show irregular bedding in appearance.

Stratigraphic relations The conglomerate covers the shale formation (Ksh3) of uppermost Cretaceous strata in an angular unconformity. No macrofossils have been found in the strata. Some of the calcareous pebbles involve fossils showing Cretaceous age, however, those fossils are not use for age determination because of their accidental origin.

The time of sedimentation of the Conglomerate is presumed to be the period during late Eocene to early Oligocene owing to the facts, 1) Severely folded structure observed in the Cretaceous system is unable to see in the Conglomerate. 2) The uppermost Cretaceous strata are unconformablely covered by the Conglomerate. 3) Andesitic pebbles are found in the Conglomerate. The basis of the consideration is that the time of the oldest volcanic activity of andesitic nature was decided to latest Eocene age by the K-Ar absolute age determina-

tion carried out in the present investigation. The Conglomerate is supposed to be terrestrial sediments unusually deposited in some basins locally formed in inland. The basis of the consideration is that the maldistribution of the Conglomerate, no sorting, clino-uncoformity between the lower Cretaceous strata.

The Conglomerate is correlative with the El Morro Conglomerate Formation (Simons and Mapes, 1956).

(2) Altered andesite lava (Tanl) and andesite dyke (Tian)

Distribution   The rocks are distributed constructing the range of 4 km x 8 km in scale to the east of Nicolás Flores settlement, and also in the north of Poterero settlement in the survey district. Beside, the rocks are observable in the form of small dykes in the surroundings of the lava.

Lithologic characters   In appearance, the rocks seem to be greenish gray, heterogeneous tuff breccia, however, in reality, hard and compact andesite lava involving many of the cognate fragments. Under the microscope, porphyritic and fluidal textures are clearly observed. Phenocrysts are composed of plagioclase, hornblende, augite and magnetite, but almost all (except magnetite) are altered to epidote. Matrix is composed of fine grains of pyroxene and felsitic part, but all (except quartz) are also changed to minute crystals of epidote.

In the dykes of small scale, the rocks are more homogeneous and microscopically, porphyritic texture is more distinct compare to the

lava. The rocks have hornblende, plagioclase, biotite, apatite and sphene as phenocryst, and lath-shaped plagioclase, quartz and grains of augite as matrix. Carbonaceous minerals, chlorite are included as secondary minerals. Dykes of these kinds swarm in the Cretaceous rocks on a small scale at the vicinity of Poterero and are considered to have been formed around the vent of lava mentioned above.

Stratigraphic relations The rocks are isolately distributed from the other volcanic rocks and seem to cover or intrude the Cretaceous strata. The rocks are considered to be one of the oldest volcanic rocks in the district owing to the absolute age (38.1±1.4 m.y.) determined by K-Ar method and to the fact that the pebbles of andesite similar to this rock are included in the conglomerate lowermost of the Tertiary strata.

(3) Acidic tuff (Ttf1)

Distribution The tuff is only distributed at the foothills southeast of Cerro Peña Colorada in the southern central of the district on a small scale.

Lithologic characters The tuff comprises the alternated layers of acidic tuff and porous, tuffaceous limestone. Thickness of the tuff is estimated at about 20 m. The characteristics of the limestone are its porous and rough appearance and its form of bedding in the shape of elongated lens.

Stratigraphic relations The tuff is covered by the basalt lava (Tbal) mention later. Direct relationship between the tuff and the

lower layer is unable to observe, however, it is presumable that the tuff covers the Hippurites limestone in an unconformity because of the wide distribution of the limestone around the area.

(4) Basaltic rocks (Tbal)

Distribution The Basaltic rocks are distributed in two areas. One is the northwestern part of the surveydistrict from the vicinity of Zimapán to the area along the national highway No. 85 in the east. The other is the southern area constructed of latitudinal mountains and small hills. Those areas occupied by the rocks are roughly estimated at 6 km x 15 km in the northwest and 15 km x 30 km in the south.

Lithologic characters The rocks are composed of two parts, namely, a part showing alternations of basaltic lava and volcanic breccia of the same characters, and a part predominated by lava flow, although the both two are lumped together.

The basaltic rocks exposed in the southern part are gray to reddish brown, various kinds from compact to porous and have fluidal texture in most cases. In this part of the area, latitudinally extended range and hills are all occupied by the basaltic rocks of this kind. Near the center of this part, the lava flows and volcanic breccias are horizontally distributed in alternations of the both, each 5 m to 10 m in thickness. In the case of this part, volcanic breccia predominates, but in other parts quite opposite. Microscopically, the volcanic breccia shows porphyritic texture and have quartz,

plagioclase, rhombic and monoclinic pyroxenes as phenocryst and lath-shaped plagioclase, tabular crystals of pyroxene and gray glass in matrix. Much of the rock show amygdaloidal vesicular texture and crystals of cristobalite fill up the inside of the bubbles.

The basaltic rocks exposed in the northwestern part are dark gray to dark green, compact and have vesicular texture. Under the microscope, porphyritic texture due to the phenocryst of olivine and vesicular texture are characteirstic. Matrix is composed of lath-shaped plagioclase aligned in a direction and large in quantity, pyroxene, olivine and magnetite. Phenocrystic olivine generally altered to chlorite or saponite.

In general, lava flow is dominant, but in the northern corner volcanic breccia of similar characteristics predominates.

As mentioned above, the Basaltic rocks exposed in the south and northwest are classified into quartz basalt and olivine basalt respectively.

Stratigraphic relations   The rocks conformably overlie the Conglomerate (Tcg) of lowermost Tertiary in the vicinity of Zimapán. Also at Cerro Peña Colorada in the south, they overlie the Acidic tuff (Ttfl).

(5) Andesitic rocks (Tan2)

Distribution   The Andesitic rocks (Tan2) are widely distributed in the Xinthe range of southwest, Actopan range of southeast and the Juarez range of north central in the survey district.

Lithologic characters   The rocks are composed of alternations of andesite lava, andesitic volcanic tuff, andesitic agglomerate and tuff breccia in the Xinthe range and Actopan range. Especially in the northern half of the Xinthe range, volcanic breccia and agglomerate is dominant.

Lithologically the rocks are roughly classified into hypersthene augite andesite and hornblende cristobalite quartz andesite. On the geological map, two varieties are bundled up as Tan2, because the two are alternatively accumulated in the area.

Hypersthene augite andesite is gray, porphyritic and microscopically, has plagioclase, augite, hypersthene and magnetite as phenocryst and the matrix is composed of lath-shaped plagioclase and fine grained pyroxene. Generally fluidal texture due to the parallel arrangement of the lath-shaped plagioclase is observable.

Quartz andesite is quite variable in its composition, namely, phenocrystic quartz, hornblende, cristobalite, hypersthene and augite are changeable in kinds and in their quantities, especially quantity of quartz crystals is insettled.

Andesitic rocks distributed in the vicinity of Juarez rangeis quite similar to others in its lithofacies, however, variety of quartz andesite is unable to see. In Cerro de Juarez, lower half of the andesitic rocks involves more volcanic breccia, and in the upper half lava flow is dominant.

Stratigraphic relations The andesitic rocks overlie the basaltic rocks (Tba1) at the western foothills of Cerro de Juarez. Absolute age determined by K-Ar method of the andesite collected at the bottom of Arroyo Cerro Blanco valley (outside of the survey district), located at the eastern foothills of the Actopan range is 27±1.4 m.y. Consequently, the age of the andesite is presumed to be in latest Oligocene.

(6) Basaltic lava (Tba2)

Distribution, lithofacies and lithologic characters The rocks are lava flow intercalated Andesitic rocks (Tan2), and are distributed on a small scale on the western slope of Cerro de Juarez range. The rocks are chloritized showing dark green in colour and have amygdaloidal texture. The rocks are conformably interbedded and thought to have been occurred by the local activity.

(7) Rhyolitic rocks (Trhy1)

Distribution, lithofacies and lithologic characters The rocks are locally intercalated between the Basalt (Tba2) in the lower and the Andesite (Tan2) in the upper. The rocks are considered to have been arised on a small scale by the local activity, because continuous extension of the rocks is unable to observe. Colour of the rocks is grayish redishbrown, and the rocks show porous and rough appearance.

(8) Acidic pyroclastics (Ttf2)

Distribution In the western part of the survey district, the rocks are widely distributed at the lower reaches of Río Túla between Xajha and Caltimacan. Besides, the rocks are distributed composing a part of the Actopan range at the northeastern part of Santiago de Anaya, the southeastern part of Actopan, both in the southeastern part of the survey district. Maximum thickness of the rocks is assumed to be about 400 m.

Lithologic characters Chiefly composed of rhyolitic tuff and tuff breccia, but rhyolite lava is predominant in some parts. Locally the rocks intercalate andesitic tuff and andesitic tuff breccia.

In the western area, the rocks are chiefly composed of rhyolitic tuff and tuff breccia of pale yellowish or pale greenish colour and intercalate the lava of reddish brown rhyolite in several horizons. Generally stratified and some parts are tuffaceous sandstone of reddish brown or greenish yellow colour. The rocks are partly chloritized and pale green in colour. Rhyolite occurred along Río Túla in the north of Caltimacan shows porphyritic and fluidal textures and partly spheroidal texture under the microscope. As phenocryst plagioclase is involved, and in the matrix plagioclase, quartz, glassy materials and a little of grains of pyroxene, magnetite are included. The rocks distributed along the national highway No. 85, in the northeast of Caltimacan are pale green, autobrecciated, glassy, biotite rhyolite or perlite. At the southern foothills of

the Actopan range, southeast of Actopan, the rocks are pale yellowish brown rhyolitic lava and pale yellow lapilli-tuff.

Stratigraphic relations The rocks overlie the Andesite (Tan2) at the west of Caltimacan and the east of Actopan. Consequently, the rocks are supposed to have been occurred by the acidic activity continued to the andesitic activity by which the Adnesite (Tan2) arised. The rocks exposed in the west, show some stratification and the direction of their strike in general is NW, and dip is 15° ∿ 25°NE or to SW and gently folded.

(9) Adnesite lava (Tan3)

Distribution The rocks construct the mountains 400 m high (in maximum, above the level of surrondings), located in between Xitha and Saucillo in the west. The thickness of the lava is thought to be 350 m in maximum.

Lithologic characters The lava is dark green or brown, porous and massive. Partly and irregularly intercalates tuff of same character, tuffaceous sandstone. Under the microscope, it shows porphyritic texture, and has plagioclase, hypersthene, augite as phenocryst, lath-shaped plagioclase, tabular pyroxene or its grains, magnetite and a little of hornblende in matrix.

Stratigraphic relations Probably the stratigraphical position of the lava is considered to be upper than the Acidic pyroclastics (Ttf2), although the relation of the lava to the other rocks was not confirmed in the present investigation.

(10) Rhyolite lave (Trhy2)

Distribution Main areas in which the lava (Trhy2) is distributed are: 1) Highland between the vicinity of Xajha in the western part of the survey district and the area in which Ttf2 of Caltimacan is distributed. 2) Mountains located in the west of Santuario in the central part of the survey district. 3) In the Actopan range in the southeast of the area.

Lithofacies, lithologic characters Main part of the Lava is observable in the form of lava dome and partly as autobrecciated lava or volcanic breccia. The lava distributed between Zimapán and Xajha is composed of gray rhyolitic volcanic breccia and pale gray rhyolitic lava having the phenocrysts of biotite and quartz. At the lowermost, the lava penetrates the Cretaceous shale formation(Ksh3) in dyke form. Microscopically, the rock shows porphyritic and spheroidal textures and includes biotite and plagioclase as phenocryst. Matrix is chiefly composed of quartz and plagioclase and shows spheroidal or myrmekitic texture and in additional grains of pyroxene and magnetie are observed in a small quantity. Result of chemical analysis shows 75.40% of SiO_2, 2.59% of Na_2O, and 4.49% of K_2O in composition and is correspond ro rhyolite.

The lava forming an isolated mountain at the west of Santuario is distributed in an area of 2.5 km x 5 km and shows pale gray to pale pinkish gray, compact and porphyritic or fluidal in texture. Macroscopically orthoclase and quartz are observable in abundance and biotite and hornblende are also present in a small quantity as

phenocryst. Microscopically, it shows porphyritic and fluidal textures, phenocrysts are sericitized orthoclase, quartz, biotite, hornblende and magnetite and the matrix chiefly comprises potash feldspar and quartz and additionally minute grains of pyroxene and magnetite. Mention later in the chapter of mineral deposit, some parts of the lava include gold in economic value. Total chemical analysis of the lava shows 72.31% of SiO_2, 0.75% of Na_2O, 9.06% of K_2O, and the normative orthoclase reaches to 53.5%. Consequently, the lava seems to be a variety of potash rich rhyolite rarely observed in the survey district.

Stratigraphic relations The lava overlies the Cretaceous shale (Ksh_3) directly in the east of Xajha and in the north of Santuario, and the Cretaceous limestone (Klf) in the south of San Clemente. However, the lava also overlies the Tertiary andesite (Tan_3) in the mountains located in the west of Xitha. Absolute age of the lava in the form of dyke located in the east of Xatha is 27.1±1.4 m.y., and the lava in the west of Santuario shows the age of 26.5±1.3 m.y. Owing to these values the age of eruption of the lava is considered to be late Oligocene.

(11) Basalt (Tba_3)

Distribution The basalt occupies the gentle hills, about 6 km northwest of Puerto de Las Trancas in the northern area, and is distributed about 6 km longitudinally. The thickness of the basalt is supposed to be 150 m in maximum.

Lithofacies, lithologic characters   Dark blueish gray, compact, aphanitic and massive lava. Lower and upper parts have platy joint, and the thickness of each plate is ten to thirty centimeters. In the middle part, columnar joints are developed in several meters intervals. No intercalation of pyroclastics is observable. The rocks belong to augite basalt.

Stratigraphic relations   The lava overlies the Cretaceous system in the north of distributed area and in the south at the Tertiary basalt (Tba_1). Each distribution is separated and assumption of the period of eruption is rather difficult. However, the period is considered to have been the latest among the Tertiary volcanic rocks, due to the topographical feature of the area occupied by the Lava. Those areas are not so much eroded.

IV-2-3 Quaternary System

Quaternary system is widely distributed in the broad plains and sub-montane area from the central part to the south of the survey district. In the north, there is no distribution of the system. The system is composed of weakly consolidated, stratified sand and grabel beds, and stream sediments covering the beds along the narrow reaches of Río Actopan and Río Túla.

The former intercalates volcanic ash bed and some basaltic lava, and as a whole, shows horizontal stratification. Distribution of the former is in a range from the plain 1,700 m in altitude to the foothills 2,200 m high. The former is considered to be the inland lake deposits sedimented

in some structural basins or eroded basins in late Tertiary to Quaternary period.

Details concerning on the Quaternary system will be omitted in the report because those are beyond the scope of the present work.

IV-2-4 Intrusive Rocks

Three kinds of intrusives such as granodioritic (Tigd), andesitic (Tian), rhyolitic (Tirh) rocks are found in the district, all of which intruded into the Cretaceous sedimentary rocks in the northern half of the survey district.

(1) Granodioritic rocks (Tigd)

Distribution The rocks are distributed in the following areas

(a) It scatters as stocks (eight bodies in large and small size) for about 15 km from the vicinity of El Zapote to the west of San nicolás in northern part of the survey district.

(b) In the vicinity of Maguey Verde (two large and small bodies) to the northwest of El Zapote.

(c) To the north of Nicolás Flores (nine small bodies in the shape of stock and dyke).

(d) To the north of Poterero (seven small bodies of stock).

(e) In the vicinity of Pechga (two small dykes).

(f) In the vicinity of Bonanza.

(g) To the west of Zimapán.

The largest body among these is the one located to the west of San Nicolás, which is about 1.5 km in width in E-W direction having elongation of about 5 km in N-S direction. The distribution of these granodioritic intrusives shows roughly a tendency that they are arranged into two directions such as NE-SW and NW-SE. The rock in the neighborhood of Zimapán is separately distributed in the western part of the survey district.

Lithofacies and lithologic characters   The rocks are dioritic to granodioritic in composition, and from holocrystalline to porphyritic in texture. The rock to the west of San Nicolás are dark gray, medium-grained, holocrystalline quartz diorite, and the mafic minerals are augite, hypersthene, amphibole, biotite, rutile, and magnetite. A result of the whole rock chemical analysis in this time shows 56.95% SiO_2, 3.25% Na_2O, 2.02% K_2O, which corresponds to granodiorite of Bateman's classification (1963) in normative minerals. The rock in the vicinity of El Zapote is a little porphritic and hypabyssal, and changes its lithology from quartz dioriotic part (the periphery) to monzonitic part (the center part). The constituent minerals are, in every case, plagioclase and quartz, and minor amount of orthoclase, augite, hypersthene, amphibole, biotite, rutile, apatite, and magnetite, though changes are observed from medium-grained and holocrystalline to porphyritic in texture and from quarts diorite to granodiorite in composition.

The most common alteration is argillization by weathering, but chloritization and epidotization of amphibole and biotite can be observed in many instances. Also the rocks in the vicinity of El Zapote mine, Pechuga mine, and Poterero are partly subjected to skarnization.

These granodioritic rocks have a close relation to contact metasomatism and hydrothermal alteration taken place in the survey district, and a number of ore deposits such as Encarnación, El Zapote, Pechuga, Los Balcones, and Lomo de Toro were formed in the surroundings of the intrusive rocks.

Age of intrusion   The result of absolute age determination in this survey by K-Ar method shows that the rock to the west of San Nicolás is 40.5±2.0 m.y. and the rock at Encarnación is 50.9±2.5 m.y., which indicates that the time of intrusion and consolidation of these rocks is from early to late Eocene. About the intrusive rock to the west of Zimapán, it is, however, a subject of problem to consider the time of intrusion as to be contemporaneous to the rocks mentioned above because it is far separated from other rocks, a little more acidic in lithology, and is strongly hydrothermally altered.

(2) Andesitic rocks (Tian)

Distribution   The rocks are exposed in dyke and sill forms in many places along the road at Arroyo Cuesta Colorada to the north of Nicolás Flores and in the vicinity of Poterero to the south of it.

Lithofacies and lithologic characters   The rocks in the surronding area of Nicolás Flores are greenish porphyritic rock with remarkable amount of tabular plagioclase, 5 mm ∿ 10 mm in length, long prismatic amphibole, and some amount of biotite. Chloritization and pyritization are common, and the surface is oxidized to be brownish in color, The rocks caused thermal metamorphism to the surrounding sedimentary rocks, which gave rise to the presence of shaly rocks metamorphosed to spotted hornfels and garnet-epidote hornfels.

The result of the whole rock chemical analysis in the vicinity of Poterero gives the values such as 51.81% SiO_2, 15.85% Al_2O_3, 3.14% Na_2O, 4.10% K_2O, indicating that the rocks are basic andesite to basalt moderately rich in alkali.

Age of intrusion   Absolute age of the rock in the vicinity of Poterero by K-Ar method is 38.1±1.9 m.y. indicating the age of late Eocene.

(3) Rhyolitic rocks (Tirh)

Distribution   The rocks occurs as small dykes in four places-Yonthe mine, Poterero, to the northwest of Nicolas Florás, and in the vicinity of Dexhi to the west of Zimapán.

The rock located to the northwest of Nicolás Flores interpentrates into Cretaceous sedimentary formation (Ksh3) in the form of a sill, five meters in width, continuing for about one kilometer. The rock

in the vicinity of Poterero is a dyke, several meters wide and about 10 m long, which is observed between the andesite dyke (Tian) and the Cretaceous shale formation (Ksh3). The rock in the vicinity of Daxhi to the west of Zimapán forms a dyke in the surrounding area of a lava dome of rhyolite (Trhy2).

Lithologic characters

The rocks are megascopically grayish white to yellowish gray in color, compact and fine-grained, having porphyritic texture, under the microscope, with phenocrysts of quartz and plagioclase and minor amount of biotite. Matrix consists of spherulite, quartz and sericite.

Age of intrusion   Since the rock penetrates andesite dyke (Tian) and is distributed in the surrounding area of rhyolite lave (Trhy2), it is considered that it intruded as dyke contemporaneously to rhyolite lava (Trhy2). Thus the age of intrusion is estimated to be late Oligocene.

IV-3 Geological Structure

The extent of development of geological structures observed in the survey district varies greatly in each rock distributed excepting for primary structures.

The first characteristic is that, in contrast to the development of structures such as intense folding, faulting, and warping in Cretaceous sedimentary rocks, these structures could not be almost observed in

Tertiary rocks. The second characteristic is that a thick bed of limestone which is thickly bedded and massive and considered to be the lowest formation of the Cretaceous sedimentary rocks has a little more gentle structure when compared with the two upper formations which is rich in lutaceous rocks. Beside these, it is observed that the limestone formation distributed from the central to south-central parts of the survey district shows a different direction of folding axis compared with the Cretaceous rocks distributed in other areas.

It is an interesting phenomenon that there can be observed a certain direction in the distribution of intrusive and volcanic rocks, and in the shape of rock bodies of Tertiary age.

The details of the structures are as follows:

Direction of folding axis

The direction of axis of folding structure observed in Cretaceous sedimentary rocks which is distributed in the northern half and the eastern part of the survey district is NW-SE in general. However, the rocks show a tendency of changing the direction to N-S and further to NNE-SSW in the area from the central part to the south-central part. Such change in the tendency of warping is also observed in the neighboring areas of Juárez and Pechuga which are located slightly in the north of the central part of the district.

Thus the direction of axis of folding developed in Cretaceous sedimentary rocks is NW-SE in general, but the tendency of warping toward NNE-SSW is partially observed.

Intensity of folding   There can be observed repetition of gentle anticlinal and synclinal structures, about 20° in the dip of strata, in the massive limestone formation (Klsl) which extends from the northern end of the survey district to the southeastern direction. On the other hand, intense minor folding with steep dip (in the shape of intrafolial folding) is developed in the flint-alternated formation (Kshl, Klf, Ksh2) and the shale formation (Ksh3) which overlie Klsl. The flint-alternated formation is distributed showing overturned fold from Las Trancas to southeast, in the vicinities of the Yonthe mine, and Pechuga - Bonanza.

It is therefore, considered that, in contrast to the relatively gentle structure shown in the massive limestone formation of the lowermost part, the intense folding structures occurred in the two upper formations will represent the difference of resistivity against the structural movement of each formation. It is observed that accordion pleats-like intraformational structures are developed in the upper two formations rich in lutaceous rock, having weak resistivity to structural movement.

Warping of the folding axis against their general trend are locally observed, and is considered to be secondarily formed by Tertiary igneous activities after the formation of the Sierra Madre Oriental range in which Cretaceous sedimentary rocks were primarily folded by Laramide orogeny.

Fault   Two fault systems are observed: the one is in the direction of NW-SE parallel to the axis of folding, and the other is in the direction of NE-SW ∿ ENE-WSW which is nearly perpendicular to the former and truncates the Cretaceous system.

Among the faults of NW-SE direction, the fault which is found along the western boundary of the massive limestone formation (Klsl) in the eastern part of the district is big one, and other several faults are observed at the northwestern periphery of the survey district. It is estimated that the throw of these faults is considerably great.

As the fault system of NE-SW ∿ ENE-WSW direction, several faults running approximately parallel to the national highway No. 85 in the northcentral part and a fault which runs in ENE-WSW direction at the central part, are found in the district. The former shows dip shift of small amount and strike shift of moderate sizes. Intrusive rocks were distributed along these faults.

The fault found in the central part of the survey district is assumed to extend west-southwestward from Grutas de Tonaltongo located in the east-central part, but it could not be observed in the field because of the thick cover of Quaternary system.

Some difference of sedimentary environment (the relation of contemporaneous heterotopic facies) can be observed in part of the rocks of Cretaceous system which might correspond each other putting the inferred faults between them.

From these facts, it is considered that there is a possibility that the NE-SW ∿ ENE-WSW system would have reflected the basement structure.

IV-4 Geological History

The Nevadan orogeny which originated in late Jurassic period resulted in

the formation of an uplifted geanticline in the western part of North American continent, and Rocky and Mexican miogeosynclines were formed on the east of it (Fig. IV-1). In the survey district which is located at the southern end of Mexican miogeosyncline, various marine sediments were predominantly deposited until Cenomanian stage with the development of geosyncline. However, from Turonian to Maestrichtian stage when the geosyncline was going to its termination, submergence and regression repeatedly occurred, which led to the predominant deposition of lutaceous and sandy sediments with abundant supply of terrestrial clastic sediments.

The Hippurites reef limestone which is correlated to Turonian stage is distributed in the southern half of the survey district, while the flint-alternated formation which is considered to be the contemporaneous heterotopic facies with the former is mostly distributed in the nothern half. This indicates the difference of sedimentary environment between the northern and southern halves of the district during the Turonian stage. It might also warrant the existence of ENE-WSW trending basement structure which divides the survey district into two parts, northern and southern halves.

As the result of Laramide orogeny which continued from the latest Cretaceous to early Eocene of Tertiary, the sediments in the geosyncline were folded by great compressive forces and were uplifted to make the land. It is considered that with the release of compressive forces toward the end of orogenic movement, normal fault of an open system parallel to the strike of the formations was formed first, and after that, the truncate fault in NE-SW ∿ ENE-WSW direction which might have reflected the

basement structure went into action.

After the termination of Laramide orogenic movement, intrusion of granodiorite took place as a precurssory igneous activity.

The distribution of intrusive rocks is controlled by the faults of two systems. The K-Ar absolute age of these rocks shows 50-40 m.y., and they were not affected by any structural movement.

The igneous activity continued through the Quaternary to the present, although it is a characteristic of the district that the volcanic activity is concentrated in Oligocene time. Some flexure structure can be observed in part of the Cretaceous system affected secondarily by these volcanic activities.

IV-5 Ore Deposit

IV-5-1 General Features of Ore Deposits

The survey district is divided into two parts from the standpoint of metallogenetic province; the northern half which belongs to the Sierra Madre Oriental province and the southern half which is contained in the Younger Volcanic province (Salas, 1975).

The ore deposits in the Sierra Madre Oriental province mainly consists of pyrometasomatic to hydrothermal type deposits which are related to the Tertiary intrusive rocks and occur in the Mesozoic sedimentary rocks. They take various shapes such as vein, chimney, manto, and massive (Zimapán mining area, northwest in the district). The representative type of the deposit belonging to the Younger Volcanic province can be

observed in the mineralized zone from Pachuca to Real del Monte, which occur in Tertiary volcanics as vein-type epithermal deposit.

The survey results in this phase shows that the ore deposits and the showings are concentrated in the northern half of the district, and they mainly consist of pyrometasomatic to hydrothermal type which are formed along the contact between the Tertiary intrusive rocks and the Cretaceous sedimentary rocks, and their surroundings except for only one instance. Generally speaking, it can be said that the ore deposits found in the district show the similar character to those of the Sierra Madre Oriental province. However, the chemical analysis of the ores from the deposits and showings within the district shows noticiable contents in gold and silver.

This indicates that the character of ore deposit and showing within the district is not indifferent to that of the deposits found in the Younger Volcanic province in terms of the fact that both mines of Pachuca and Real del Monte were gold-silver mine.

IV-5-2 Distribution of Mineralized Zones

Mineralized zones which contain the known ore deposits within the district are concentrated to the areas in which intrusive rocks are distributed, as shown in table IV-5 and Fig. IV-7.

(1) Six mineralized zones associated with the granodioritic intrusive rocks.

  I. San Antonio- La Luz

Table IV−5 List of Mineralized Zone

No.*	Mineralized zone		Mine or showing **	Type of ore deposit	Related igneous rock	Remarks
I	San Antonio -La Luz	3	San Antonio	manto, hydrothermal	granodiorite dyke	under operation
		4	La Luz	" "	"	"
II	Dos de El Aguila	5	Dos de El Aguila E.	chimney, "	"	—
		6	" W.	manto, "	"	—
III	Encarnación	7	Delicias	pyrometasomatic, massive	granodiorite stock	—
		8	Santo Domingo	"	"	—
		9	Nameless	"	"	—
		10	El Cambio	"	"	—
		11	Corral Viejo	"	"	—
		12	La Cueva del Tejon	"	"	—
		13	Santo Tomás	"	"	—
		14	Dulces Nombres	"	"	—
		15	Aguila Roja	"	"	under operation
		16	San Francisco	"	"	—
		17	Rigel	"	"	—
		18	Socorro	"	"	—
IV	El Zapote	19	El Conejo	"	"	—
		20	Nameless	"	"	—
		21	Ignacio Zaragoza	"	"	under operation
		22	San José del Oro	"	"	—
		23	Corcus	"	"	—
		24	Santa Eleanora	"	"	under operation
		25	La Trinidad	"	"	"
		26	Concordia	"	"	—
		27	Los Gallos	"	"	—
V	Zimapán	28	San Francisco	pyrometasomatic, hydrothermal, manto, chimney	monzonite stock	—
		29	San Miguel	"	"	—
		30	Los Balcones	"	"	under operation
		31	La Prisima Fresnillo	"	"	"
		32	Lomo de Toro	"	"	"
VI	South Zimapán	33	María Antonietta	hydrothermal, vein	"	"
		34	Guadalupe	"	"	—
		35	Nameless	"	"	—
VII	Potrero	36	Nameless	hydrothermal, vein	granodiorite dyke	—
VIII	Pechuga	37	Santa Elena	pyrometasomatic, hydrothermal	granodiorite dyke	—
		38	"	manto and massive	"	—
		39	San Miguel	"	granodiorite dyke, granophyre	under operation
IX	Yonthe-San Joaquin	40	Providencia	hydrothermal, chimney	unknown	—
		41	San Joaquin	"	"	—
		42	San Vicente	"	"	—
		43	Las Aminas	"	"	—
		44	San Bernardo	"	"	—
X	San Clemente	45	San Clemente	hydrothermal, disseminated	potash rhyolite	under operation

*, ** Number of the mineralized zone and mine corresponds to the number on PL. 4 and Fig. IV-7.

II. Dos de El Aguila

III. Encarnación

IV. El Zapote

VI. Poterero

VIII. Pechuga

(2) Two mineralized zones associated with monzonitic intrusive rocks

V. Zimapán

VII. South Zimapán

(3) One mineralized zone associated with the potash-rhyolite lava dome

X. San Clemente

(4) Other

IX. Yonthe-San Joaquin

The arrangement of these zones was naturally controlled by the distribution of intrusive rocks. Especially the arrangement of mineralized zones within the surroundings of granodioritic intrusives shows remarkablly a character that the intrusive rocks are distributed in two directions of NW-SE and NE-SW reflecting the fault system in the district.

Details on the arrangement of mineralized zone surrounding the monzonitic intrusive rocks could not be known because the rocks are distributed extending beyond the boundary of the survey district. The mineralized zone associated with the potash-rhyolite lava dome is distributed independently. However, the mineralization associated with potash-rhyolite should be studied in detail in the future for the special characteristic of mineralization that gold and silver are disseminated in part of the

rock without any sillicifcation and other mineralization, and because the rock itself has a peculiar character in potash contents.

IV-5-3 Details of Mineralized Zones

Description was made on the mines which represent each zone.

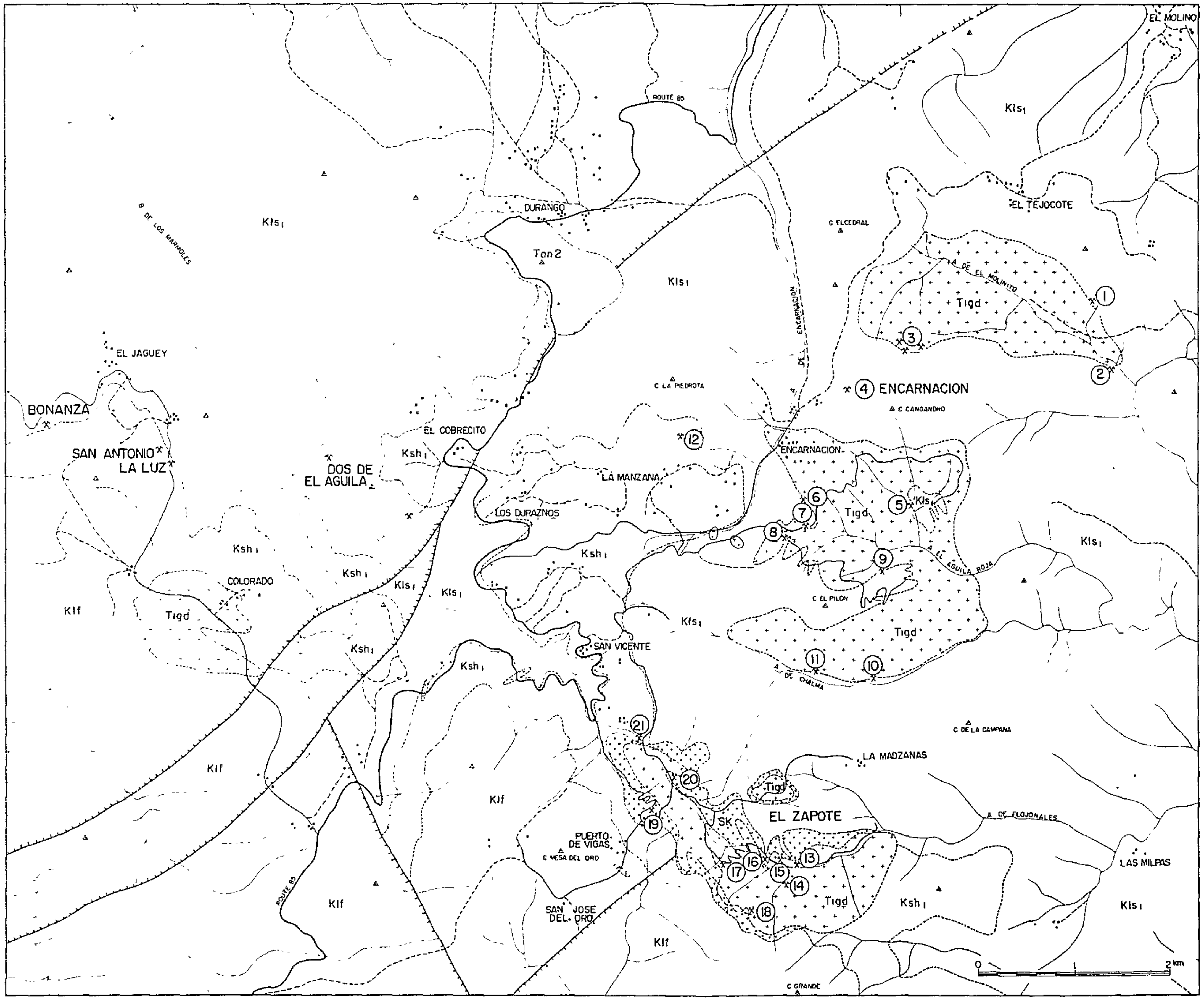
I San Antonio-La Luz zone (La Luz mine)

Location It is located 3.5 km to the north-northwest of Maguey Verde village.

Occurrence It is a manto type deposit embedded along the bedding of the country rock composed of the Cretaceous sedimentary rocks. The hanging wall of the deposit consists of alternation of thin-bedded shale and siltstone, while the foot wall consists of grayish white massive limestone. The thickness of the ore is one to two meters, which is observed along a winze excavated along the ore body which has the dip of about 10° for about 30 m. Because of only one narrow winze, extention of the deposit along the strike was not confirmed.

Ore and gangue minerals The ore is comprised of oxidized ore in which bandded structure is partly seen. Main ore minerals are hematite, limonite, and jarosite, ana a little amount of the dissemination of manganese dioxide is also observed. Calcite was the only gangue mineral to be found. Limestone on the foot wall is completely recrystallized, and silicified a little.

The result of analysis is shown in the following table.



LEGEND

Ton2	Tertiary andesite lava
Tigd	Tertiary intrusive rock
Klf	Cretaceous flint-alternated limestone
Ksh1	Cretaceous shale
Kls1	Cretaceous massive limestone
SK	Skarn
	Fault
	Mine
	Highway
	Unpaved road
	Trail
	Drainage

Encarnación mine

1 Delicias
2 Santo Domingo
3 (Nameless)
4 El Cambio
5 Aguila Roja
6 La Cueba del Tejon
7 Santo Tomás
8 Dulces Nombres
9 San Francisco
10 Socorro
11 Rigel
12 Corral Viejo

El Zapote mine

13 La Trinidad
14 Concordia
15 Santa Eleanora
16 Corcus
17 San José del Oro
18 Los Gallos
19 Ignacio Zaragoza
20 (Nameless)
21 El Conejo

Fig. IV-5 Location Map of Metal Mines in the Encarnación-El Zapote Area

Table IV-6 Metal Contents of Ore Samples from the La Luz Mine

No.	Sample No.	Mine	Au g/t	Ag g/t	Cu %	Pb %	Zn %	Remarks
1	Da44C	La Luz	21.7	720.0	0.006	12.05	0.11	limonite-jarosite ore
2	Da45C	ditto	4.8	475.6	0.027	2.57	0.38	hematite ore
3	Da46C	ditto	tr.	1.2	0.002	0.012	0.082	manganese oxide ore
4	Da47C	Bonanza	0.5	1995.1	0.031	0.60	0.14	

As shown in the table, the ore of this mine contains mainly gold and silver, and partly lead shows considerable value.

It was told that mine owner is Arberto Magos, a resident of Mexico City. The ore is mined in a small scale with pick and hammer by a few local peoples to produce about 50 tons per month.

The San Antonio mine is located about 200 m to the northwest. It has the same type ore deposit to the La Luz mine, but it was closed at the time of survey.

Relation with igneous rocks   No direct relation with the igneous rocks was observed. It is considered, however, that the ore was formed by hydrothermal solution brought from the granodioritic rocks because the rocks are extensively distributed to the west of these mines being associated with mineralization and also because of recrystallization and silicification to be observed in the foot wall limestone.

II Dos de El Aguila zone

Location It is a general name of the two showings which are located opposite to the La Luz mine across a creek, about 1.5 km to the east.

History It is said that several vertical shafts were sunk by 10 ∿ 15 workers 30 ∿ 45 years ago to pick up ore, but they are closed at present.

Occurrence Two main showings were observed. The east one is manto-type oxidized deposit with foot wall of thick-bedded limestone and hanging wall of medium- to thin-bedded marly limestone.

The mineralized zone extends strikewise more than 500 m indicating a fairly large scale of the zone. The thickness of the deposit could not accurately be measured because of the overburden made difficult to observe the whole section, but it was assumed to be about 15 m.

About 750 m to the west, a chimney-like ore deposit is found, which is formed in thick-bedded limestone with an elliptical section on the surface with minor axis of 10 m and major axis of 30 m.

Ore and gangue minerals Hematite and limonite are main ore minerals, and jarosite and magnetite are found a little. Chalcopyrite is rarely observed. Calcite is the only gangue mineral. The limestone within the surrounding area is completely recrystallized to marble, in which calcite veins and quartz veinlets were observed.

The result of chemical analysis of the ores taken from these ore bodies are shown in the following table.

Table IV-7 Metal Contents of Ore Samples from the Dos de El Aguila Mine

No.	Sample No.	Au g/t	Ag g/t	Cu %	Pb %	ZN %	Remarks
1	Dd149C	0.3	16.2	0.004	4.72	0.098	manto-type ore
2	Dd151C	0.2	5.8	0.042	2.36	0.31	manto-type ore
3	Dd153C	0.1	34.5	14.49	0.016	1.62	chimney-type ore
4	Dd155C	0.1	126.5	0.52	0.032	1.19	chimney-type ore
5	Dd157C	0.2	4.9	0.34	0.012	0.082	chimney-type ore

Relation with igneous rocks A small dyke of granodiorite is found 10 m apart to the west of the chimeney-shaped ore body. The limestone of the neighboring area is extensively recrystallized and is partly hydrothermally altered. Therefore, it is considered that the deposit was formed by hydrothermal solution derived from the intrusive igneous rock.

The result of assay shows erratic concentration of silver, copper, lead, and a little amount of gold.

Consideration The zone of mineralization is fairly extensive, containing the chimney- and manto-type ore deposits. In particular, the manto type deposit seems to extend flatly along the boundary between the thick-bedded limestone and the medium- to thin-bedded marly limestone. Therefore,it should be necessary to investigate the conditions of ore deposit in this zone.

III Encarnación mineralized zone

Twelve mines and showings are distributed centering a stock of granodiorite which is emplaced with an area of 2 km × 2 km on the surface. Among these, a deposit is found in the limestone which takes a shape of roof-pendant, and other eleven are located at the contact between the intrusive rock and the massive limestone which was intruded by the former.

History It is said that those mining area was developed since relatively old time because of easy access being located in the proximity of the highway. At present time, however, most of the mines were closed, only Aguila Roja mine is being operated.

The mine was developed in about 1973. At present 15 miners including the mine manager is working to produce the ore of about 100 tone per day.

Occurrence The ore deposit distributed with intermittent continuation of irregular, massive to lenticular ore bodies emplaced along the contact between the massive limestone and the stock-like intrusive rock which has granodioritic to quartz dioritic composition showing slightly porphyritic, hypabyssal structure. The unit ore bodies are small in size. The Aguila Roja ore deposit being operated at present is massive in the shape with a dimension of about 30 m × 50 m × 50 m.

Ore and gangue minerals Magnetite is the most abundant ore mineral. Pyrite, chalcopyrite, pyrrhotite, and sphalerite as accessory minerals. Secondary minerals such as hematite, limonite, and covel-

line are sometimes observed. Garnet is a main gangue mineral associated with wollastonite, epidote and calcite.

The result of chemical analysis of ore samples taken from the showings are shown in the following table.

Table IV-8 Metal Contents of Ore Samples from the Encarnación Mining Area

No.	Sample No.	Mine	Au g/t	Ag g/t	Cu %	Pb %	Zn %
1	Cb119C	No name	tr.	0.9	4.51	0.007	0.063
2	Cb149PC	Dulces Nombres	0.2	0.5	0.084	0.009	0.063
3	Cb154PC	San Francisco	0.8	5.7	1.63	0.007	0.093
4	Cb156PC	ditto	0.1	2.3	1.03	0.006	0.30
5	Cb159PC	Dulces Nombres	0.1	0.7	0.13	0.008	0.060
6	Cb162PC	ditto	0.1	1.4	0.007	0.016	0.23
7	Cb164PC	Aguila Roja	0.3	1.4	0.21	0.009	0.018
8	Cb168PC	San Ricardo	0.3	2.1	2.14	0.009	0.20
9	Cb169PC	ditto	0.1	1.2	0.11	0.007	0.020

The result shows some high grades in copper, but generally low in other elements. The grade of iron is not contained in the table, though it seems to be pretty high with the naked eyes, which warrants tha the Aguila Roja is operating as an iron mine.

Consideration Numerous showings which are scattered along the indented contact between granodioritic intrusive rock and the massive limestone have been mostly explored and mined. Thus there is little

possibility of finding out new ore showing. In addition, it is a tendency of this zone that the content of the useful metals other than iron is lower than other areas. Therefore there is little room for future exploration.

IV El Zapote mineralized zone

Locality The mineralized zone consists of nine mines and showings scattered around the intrusive body of granodiorite which is located six kilometers to the south of Encarnación village, along the Arroyo de Flojonales.

The intrusive rock extends northwestward with elongation of three kilometers and width of 600 m along the Arroyo de Flojonales.

Mines and showings are scattered within the skarn zone developed in the surroundings of the intrusive rock.

History It is said that the development of the mines distributed in this zone was commenced before the 20th century, and there remains a note, 'completed in 1905' inscribed on the wall of the existing Sante Eleanora adit. In 1908, Cia. Metalurgica Mexicana S.A. conducted systematic surface exploration in cooperation with Cia. Asarco S.A., and got hold of the idstribution of the mineralized zone. The company made continuously the up-to-date exploration thereafter.
At present, La Pal of Zimapán is operating both mines of La Trinidad and Santa Eleanora. Other one company is operating at Ignacio Zaragoza.

Occurrence Ore deposits within the mineralized zone are of pyrometasomatic type embedded at the contact between limestone and granodiorite which intruded into the boundary between the thick-bedded limestone formation (kls 1) and the flint-alternated formation (Klf).

In surroundings of the intrusive rock, skarn zone of several tens centimeters to several hundred meters in width are developed, in which irregular massive to lenticular ore bodies are scattered.

Ore and gangue minerals Main ore minerals are magnetite, chalcopyrite, bornite and pyrite. Some ores contain sphalerite and native gold. On the surface, hematite, jarosite, azurite, and malachite which were oxidized from the above primary minerals are found in most outcrops. Under the microscope, pentlandite is rarely observed beside the main minerals described above.

The result of chemical analysis of the ores taken in various parts of the mineralized zone is shown in the following table.

Table IV-9 Metal Contents of Ore Samples from the El Zapote Mining Area

No.	Sample No.	Mine	Au g/t	Ag g/t	Cu %	Pb %	Zn %
1	Cb216PC	Los Gallos	1.4	313.9	13.33	0.009	0.14
2	Cb217PC	ditto	1.8	25.6	1.46	0.009	0.013
3	Cb218C	ditto	43.4	9.3	0.77	0.006	0.013
4	Cb219PC	ditto	13.8	65.6	5.06	0.009	0.15
5	Cc70C	La Trinidad	4.2	167.1	8.63	0.010	0.17

Table IV-9 - continued

No.	Sample No.	Mine	Au g/t	Ag g/t	Cu %	Pb %	Zn %
6	Cc75C	Santa Eleanora	1.0	30.0	1.90	0.012	0.27
7	Cc76C	Corcus	2.8	45.0	2.21	0.010	1.60
8	Cc77TPC	San José del Oro	13.8	56.2	8.69	0.007	0.040
9	Cc112TC	Nameless	0.5	6.30	4.42	0.009	0.47
10	Cc113C	El Conejo	0.5	30.0	3.00	0.012	0.40
11	Cc115PC	Ignacio Zaragoza	4.6	180.0	23.70	0.007	5.00

The outlock of the result of analysis of these ores shows that the ores within this mineralized zone have the character to be rich in gold and silver. Although magnetite is the main ore mineral of the mineralization in this zone like the Encarnación mineralized zone which lies close by to the north, it is different from the latter in fairly abundant content of gold, silver and copper.

At the Encarnacion area, the skarn zones which were formed at the contact between the intrusive rocks and the calcareous rocks are small in scale and discontinuous, while at El Zapote, they are large and distributed continuously. Thus it is possible to say that the scales of skarn and mineralized zones are proportional with each other.

The main gangue mineral is garnet, pale brown to pale green in color. Diopside, wollstonite, vesuvianite, epidote, calcite, and quartz are

also observed.

Consideration Since the mineralized zone which is developed in the surrroundings of the intrusive rock has been explored and developed since the old time because of its promissive appearance, there is almost no room remained for future exploration. However, as shown in PL-1 and Fig. IV-2, the distribution of granodioritic intrusive rocks relating to the mineralization has two trends of arrangement; the one is shown in the direction of NNE-SSW with scattering distribution of the rock from the west of San Nicolás in the northern part of the survey district through Encarnación to this area, and the other is shown in the direction of NW-SE which was developed centering around this area. Therefore, there is a possibility of existence of potential intrusive rocks which may be associated with mineralization in both extensions such as to the southeast and to the southwest of the area. It is considered, therefore, that the survey more in detail should have to be conducted in these two directions.

The location of mineralized zones from I to IV hitherto described and their relations are shown in Fig. IV-5.

V Zimapán mineralized zone

Location The mines which make the center of this mineralized zone are Lomo de Toro and Los Balcones both of which are located about eight kilometers to the northwest of the town of Zimapán in the gorge of Río Tolimán. The zone is called the Zimapán mineralized zone in this report together with other three mines. These mines are under

exploration, development, and operation by mining companies. However, since they are located outside the surveyed district, the detailed survey has not been carried out. The writers had the oportunity to visit two mines within the mineralized zone for study such as Lomo de Toro and Los Balcones, in which some samples were taken. The outline is described below.

History The history of development,of the mineralized zone is quite old, and it is said that it was started in 1632. The total production could not be known exactly because of lack of accurate data. It was told, however, that 10,000,000 USCY of silver, 1,500 tons of lead, and zinc of the same amount have been produced (Simons, F.S. and Mapes V., E., 1957).Most of the production in recent years is from the both mines of Lomo de Toro and Los Balcones.

Occurrence The ore deposits within the mineralized zone are distributed within a two-kilometer radius centering around the monzonitic intrusive rock. The ores contain lead and zinc rich in silver as the principal ore elements. The important ore deposits belong to pyrometasomatic and hydrothermal types, and take the shape of massive, chimney, and manto. The veins are also observed though small in size. The main ore bodies in both mines of Lomo de Toro and Los Balcones are chimney-shaped deposit, among which the largest one is found in the Lomo de Toro mine showing the dimension of 65 m × 35 m × 105 m. These ore bodies are oxidized to the considerable depth from the surface, which gradually chagne to sulfide ore in a deeper part. The main sulfide ores are pyrite, sphalerite, and

galena, and a little amount of pyrrhotite, chalcopyrite, and arsenopyrite is observed. Oxide ores such as limonite, hematite, smithsonite, jarosite, and malachite are common.

Gangue minerals in the ore bodies which are close by the intrusive body consist of garnet, diopside, chlorite, quartz, and calcite. However, those in the deposits remote from the intrusive rock are lacking in skarn minerals, consisting mostly of calcite with a little amount of quartz. Therefore it can be said to be multifarious.

The assay result of ores taken at the Lomo de Toro mine shows high contents of silver, lead, and zinc as shown in the following table.

Table IV-10 Metal Contents of Ore Samples from the Zimapán Mining Area

No.	Sample No.	Mine	Au g/t	Ag g/t	Cu %	Zn %	Pb %
1	Da201PC	Lomo de Toro: 220 ML	0.7	402.4	0.015	23.63	32.73
2	Da202PC	Lomo de Toro: Manto Nuevo	0.4	203.4	0.022	4.71	6.36
3	Da203PC	Lomo de Toro: Santa luisa-40ML	tr.	475.6	0.041	32.57	27.73
4	Da204PC	Lomo de Toro: San Vicente 40ML	0.8	365.9	0.010	26.13	0.80
5	Dc 27C	Nameless	tr.	0.5	0.017	0.01	0.012
6	Dc117C	Guadalupe	tr.	43.1	0.012	1.25	1.20
7	Dc118PC	María Antonietta	tr.	281.8	0.029	9.71	1.00

VI South Zimapán mineralized zone

This zone is adjacent to the Zimapán mineralized zone to the south,

and it seems to be included in the Zimapân mineralized zone from the general view point. However, since the ore deposits are vein type and they are contained in the survey district, the zone was separately described for the convenience sake.

Location The mineralized zone includes the María Antonietta mine located 5 km to the west of Zimapân town and other two showings including Guadalupe which is located to the southeast of the mine.

History At present, only the María Antonietta is being operated in a small scale with several workers though the time of development is exactly unknown.

Occurrence The María Antonietta mine is a vein-type, silver-bearing lead and zinc ore deposit which is emplaced in the shale formation (Ksh 3), the uppermost Cretaceous system. The width of the vein is about one meter, and it is said that the drift has been extended for 190 m. Two old pits were found within the distance of five kilometers to the southeast of the mine.

Ore and gangue minerals

The main ore minerals in the María Antonietta mine are galena and sphalerite, and a little amount of pyrite, chalcopyrite, and marcasite are observed. Gangue minerals are quartz and calcite. About 500 m to the north of the mine, a quartz monzonite dyke is found to extend in the direction of NW-SE. Pyritization and silicification are developed surrounding the dyke on the center, which leads to the assumption of the relation between the intrusive rock and the mine-

ralization like that of the Zimapán zone. Assay result of the ore is shown in Table IV-10. According to the literature (Simons,F.S. and Mapes V.,E., 1957), the mineralized zone which contains the María Antonietta mine and its northern extention is covered by private mine's concession established from 1948 to 1957, which are under operation. Therefore, it is considered that the future exploration of the zone should be directed to the southern area leaving out the mine and the northern part.

VII Poterero mineralized zone

Location, geology, and ore deposit The whole northern area of Poterero village located about 15 km to the north of Cardonal village is called the Poterero mineralized zone in this report. The geology of this zone consists of the shale formation (Ksh3), the uppermost Cretaceous, and numerous stocks of quartz diorite and dykes of andesite and rhoylite which intruded the formation. The calcareous part in the shale formation was skarnized, and pyritization and silicification are extensively observed over the whole rocks of the area. However, a small quartz vein found in a old pit was the only showing found ever in the zone, and the result of assay shows very low grade inmetallic elements. In general terms, the area is contained within the zone of distribution of intrusive rocks which shows the trend of NW-SE direction from the Dos de El Aguila zone through the El Zapote zone to this zone. It is, however, considered that any notable mineralization could not be found in this zone because the shale formation lacks in calcareous rocks, which are deveroped in

the former two zones surrounding the intrusive rocks.

Table IV-11 Metal Contents of Ore Samples from the Poterero Mine

No.	Sample No.	Au g/t	Ag g/t	Cu %	Pb %	Zn %
1	Ca50C	tr.	2.1	0.003	0.010	0.019
2	Ca206C	tr.	0.3	0.004	0.024	0.012
3	Ca207C	tr.	2.6	0.020	0.042	0.019

Consideration A large-scale hydrothermal alteration and partial skarnization are observed in this zone. No notable mineralization, however, could be found because it is in the area of distribution of the shale formation. Therefore, in the future expolaration, emphasis would have to be put on the investigation to the northeast of the area where the distribution of calcareous rocks and intrusive rocks could be expected.

VIII Pachuga mineralized zone

It is a mineralized zone which contains the San Miguel mine located one kilometer to the north-northeast of Pachuga village and the Santa Elena mine which is located further two kilometers to the north of the former.

History According to an old-timer in the vicinity, the San Miguel mine was prospected several tens years ago in a small scale. That is shown by the two old adits in the upper level. At present, exploration work is being carried out by cutting new cross-cut and drift at the lower level about 60m below the upper level.

Occurrence The rocks in the vicinity of the mine are thick-bedded limestone, and a small stock of granodiorite and dykes of grnophyre which intruded the limestone.

Two kinds of ore deposit are observed : the one emplaced in the limestone takes lenticualr to pocket-like shape, and the other is the pyrometasomatic type deposit.

In the corss-cut at the lower level, granodiorite is exposed along the wall for about several tens meters from the entrance, in which the rock is relatively fresh. Chloritization and silicification of the medium grade are observed at the contact between the granodiorite and limestone. At the same time, the limestone near the contact is skarnized to form garnet skarn, which is several meters in width, and then changes to recrystallized limestone. In the recrystallized limestone, about 100 m from the contact toward the depth, a pocket-like ore body mainly consists of galena and sphalerite is observed. The maximum thickness at the center is about 50 cm , and the ore seems to extend to the upper and lower side at relatively low angle decreasing the thickness in both dimensions. It is said that the ore body continues from the surface to the lower level with steep pitch though irregular in the shape.

On the other hand, skarn zones mainly consisting of gray-brownish green garnet are found at the contact between granophyric intrusive rock and limestone at the entrance of the old adit of the upper level and along the mine road, in which lenticular ore bodies are formed. These were oxidized and consist of hematite, limonite, malachite, etc.

The assay result of these ores shows high values in silver as shown in Table IV-12, and also it is indicated that the ore bodies in limestone are rich in lead and silver, while the pyrometasomatic deposits are rich in copper.

Table IV-12 Metal Contents of Ore Samples from the Pechuga Mine

No.	Sample No.	Au g/t	Ag g/t	Cu %	Pb %	Zn %	Remarks
1	Ca63C	tr.	394.7	0.015	32.34	20.91	lens-like ore body
2	Ca64C	tr.	74.20	0.048	0.028	1.78	"
3	Ca205PC	tr.	750.0	0.003	65.64	0.52	stock pile
4	Cd121C a	0.2	126.3	2.790	0.013	0.014	copper showing along the mining road
5	Cd121C b	tr.	34.8	5.29	0.007	0.42	
6	Cd122C	tr.	2.9	0.019	0.008	0.011	quartz vein
7	Cd125PC	tr.	243.9	0.190	2.68	11.54	stock pile

The details on the Santa Elena mine are not known, though it is said to be located two kilometers to the north of the San Miguel mine.

The intrusive rocks which are closely related to the formation of this mineralized zone belong, from the general point of view of the district, to the extention of those distributed intermittently south-southwestward from the Encarnación-El Zapote zone which is located to the north-northeast of this zone. Therefore, in the future exploration, it would be required to put emphasis on the investigation of the intrusive rocks which is to be distributed along such direc-

tion and the mineralization to be associated with them.

IX Yonthe - San Joaquin mineralized zone

Location The mineralized zone includes five old underground workings which are scattered in the mountain mass with the difference of altitude of about 600 m extending in north-south direction in a narrow zone on the north of the Cardonal village. They are, from the north, Providencia, San Joaquin, San Vicente, Las Aminas, and San Bernardo. These are called as the Yonthe - San Joaquin mining area.

History It was told that the mines were operated between 1956 and 1958, when more than eighty miners worked and produced 100 tons of ore per day, but all are closed at present. In every place of the mineralized zone, old workings such as drifts, shafts, and open pit can be seen. Some remains of buildings which are thought to have been the mill and smeltery can be also found. It is said that the mining right is held by Cia. Mina de Real del Monte S.A. at present.

Ore deposit At present, most of the underground workings are closed, so that the details can not be known. It was assumed from the distribution of shafts and levels that the ore deposits were formed in limestone in the shape of irregular mass and chimney and continued intermittently down and upward with steep dips.

Ore minerals found at the outcrops are limonite, hematite, goethite, and jarosite. Main gangue mineral is calcite, with a little amount of quartz and wollastonite. The country rock composed of limestone is completely recrystallized. No igneous rock was found in the proximity

of the ore deposit.

The result of chemical analysis of the ore samples taken from the outcrops shows considerably low grades as shown in the following table.

Table IV-13 Metal Contents of Ore Samples from the Yonthe-San Joaquin Mining Area

No.	Sample No.	Mine	Au g/t	Ag g/t	Cu %	Pb %	Zn %	Remarks
1	Cb34C	San Bernardo	tr.	2.6	0.006	1.57	1.32	outcrop
2	Cb301C	ditto	tr.	7.1	0.006	0.87	1.00	"
3	Cd209C	San Vicente?	0.3	5.8	0.005	0.016	0.27	"
4	Cd211C	San Vicente	tr.	11.2	0.002	0.040	0.23	"
5	Cd214C	San Joaquin	tr.	4.9	0.003	0.16	19.23	"
6	Cd215C	San Vicente?	tr.	12.2	0.003	0.021	0.16	"
7	Cd260C	Las Aminas	tr.	44.6	0.007	0.94	0.30	"

Consideration Judging from the features of distribution of old pits and underground workings, it is estimated that the development and operation in this mineralized zone were stopped due to exhaustion of the ore reserves. Therefore, much fruits of the future exploration in this zone can not be expected.

X San Clemente mineralized zone

Location The mineralized zone includes all of potassium rhyolite bodies disributed at the gold mine of San Clemente and its surrounding area located about 21 km to the north-northeast of Ixmiquilpan. The

villages in the neighborhood are San Clemente one kilometer to the west of the mine and Santuario about three kilometers to the east.

History   Although the time of development of the mine is not exactly known, it was told that it had been operated in a small scale in old time. It is said that, at that time, the ore was pulverized in the stone-mill and native gold was obtained by sluicing. The stone mills can be found at the bottom of creeks nearby. After a long pause of operation, the mine was reopened, in which several workers are working by pick and hammer.

Occurrence   The ore deposit shows a unique occurrence of gold different from what can be observed in the ordinary gold deposit. The country rock of the deposit is a fresh rhyolite.

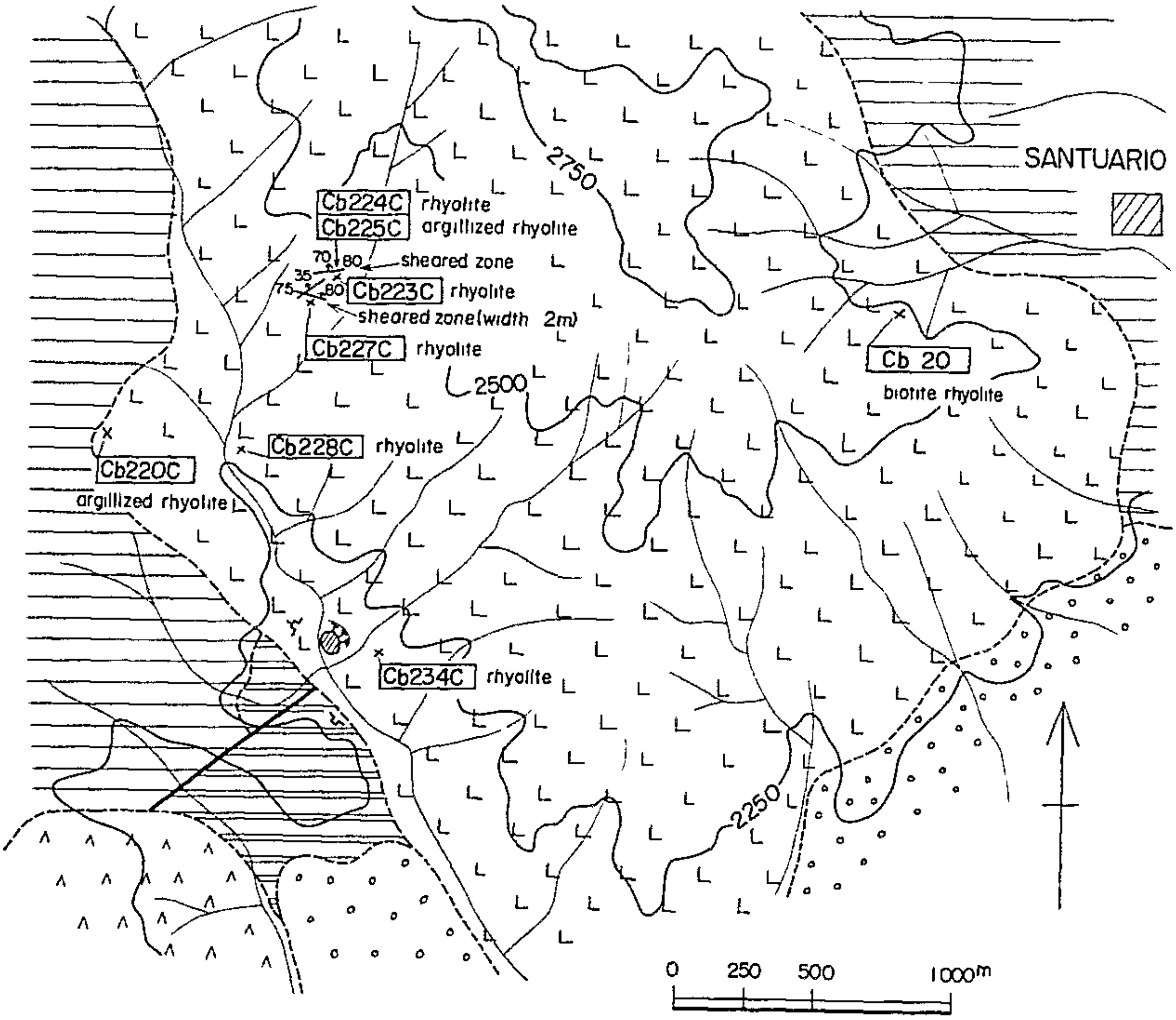
The present working faces are in several open cut which are arbitrarily excavated toward the inner part of the hill within the width of about 70 m along the hill slope.

The rhyolite which is found at the working face is developed with irregular cracks without any definite direction and the slightly argillized part showing some kinds of trend such as N 85°E, N 55°E, and N 75°W showing no consistency.

When mining the ore, they extract all these rhyolite without any discrimination from the open cut.

At the working place, no silicifcation, pyritization, nor quartz veins can be observed, so that the size of zone of mineralization

Fig. IV-6 Sample Location Map of San Clemente Area



Chemical Analysis of Samples

Sample No	Au g/t	Ag g/t	Cu %	Pb %	Zn %
Cb 20	0.13	41.9	—	—	—
Cb220C	15.4	7.9	0.065	0.027	0.098
Cb223C	0.13	17.1	—	—	—
Cb224C	0.11	21.0	—	—	—
Cb225C	22.7	7.3	0.010	0.11	0.14
Cb227C	0.62	7.6	—	—	—
Cb228C	0.13	7.6	—	—	—
Cb234C	0.94	22.5	—	—	—

LEGEND

- gravel, sand and silt
- rhyolite
- basalt
- shale, calcareous shale
- limestone, marl and shale
- 70 80 strike and dip of sheared zone
- fault
- tunnel
- Cb 20 location of sample

and hydrothermal alteration can not simply be determined.

The location and assay result of ore samples taken in this survey are shown in Fig. IV-6. According to it, the slightly argillized rhyolite taken at the working face of the mine shows the values; 22.7 g/t Au, 7.3 g/t Ag, 100 ppm Cu, 1100 ppm Pb, and 1400 ppm Zn. The slightly argillized rhyolite which was sampled at a place about 900 m to the southwest apart from the working places shows 15.4 g/t Au, 7.9 g/t Ag, 650 ppm Cu, 270 ppm Pb, and 980 ppm Zn, both of which shows very high assays. The result of analysis of rock samples taken from other places within the rhyolite body shows 0.13 ∿ 0.94 g/t Au and 7.1 ∿ 41.9 g/t Ag, which indicates very high contents of gold and silver in comparison with other rocks.

Shape, composition, and age of effusion of the rhyolite   The rhyolite body occupies an area of E-W width of 2.5 km and N-S elongation of 5 kilometers, making an independent mountain mass which rises from the surrounding plain with relative height of 750 m. It is considered that the rock partly intruded the Cretaceous shale formation and formed a lava dome overlying it.

Megascopically, the rock is grayish brown to pale pinkish gray in color, and phenocrysts of orthoclase and quartz are distinct. Flow structure is sometimes observed. The rock is generally fresh. The whole-rock chemical analysis shows 72.31% SiO_2, 13.77% Al_2O_3, 0.75% Na_2O, and 9.06% K_2O. It is shown that this rhyolite is anomalously rich in K_2O component. Accordingly, the normative orthoclase reaches as much as 53%. The value of absolute K-Ar age determination

was 26.5±1.3 m.y., which shows that the age of effusion was late Oligocene.

The size of mineralized zone and future exploration   Considering the occurrence of gold, the ore deposit might be called "potassium rhyolite gold dissemination type" ore deposit.

The value of potassium is anomalously high, and the contents of gold, silver, and other base metals such as copper, lead and zinc are high throughout the rock at least within the area in which the samples were taken. Although weak argillization was observed, other notable hydrothermal alteration and any quartz vein could not be observed.

It is, therefore, possible that the mineralization was primarily related to the volcanic activity of the rock and pervaded the whole rock. Therefore, it is considered that the zone is recommendable for one of the most important areas to be investigated by geochemical and geological survey in the second phase of the project.

IV-5-4 Microscopic Observation and EPMA Analysis of Ore Samples

Some of the samples collected in the present investigation were prepared for microscopic study and for EPMA analysis. By those samples, paragenesis of minerals were studied and argentiferous minerals were separately identified. Data obtained by the studies, such as mineral species, photomicrographs and results of the EPMA analyses, are collectively attached in the appendices at the end of this report.

Here, the results will be mentioned briefly.

Ores from the Encarnación mine In the ores, euhedral magnetite is the main component and clotty pyrite is often observable. Besides, pyrite, pyrrhotite and chalcopyrite fill the spaces of magnetite and garnet. Chalcopyrite is accompanied by a small quantity of sphalerite. Pentlandite having fine lattices of chalcopyrite, and bismuth telluride in chalcopyrite, are observed in one sample. These primary minerals are suffered from secondary replacement, namely, magnetite is replaced by hematite and goethite, and the sulfide minerals are changed into secondary sulfide or, furthermore, into hematite and goethite. Commonly the surface of the samples is covered by malachite and azurite. Under the microscope, magnetite having a widmannstätten figure which shows the process of hematitization is observed. Chalcopyrite is mostly changed to chalcocite or covellite from its margin. Furthermore, outer side of the chalcocite or covellite is ringed concentrically by fine bands composed of hematite, goethite and other translucent minerals showing a liesegang structure. In one sample, grains which fill the spaces of magnetite are supposed to have been pyrrhotite, however, at present the crystals are replaced by marcasite showing a banded structure perpendicular to the elongation axis of the grain.

Ores from the El Zapote mine Two kinds of ore, namely, one associated with magnetite and sulfide minerals and the other with only sulfide minerals, are recognized. The former is from the adits of Corcus, Santa Eleanora, La Trinidad, El Conejo, and the latter from those of Los Gallos, San José del Oro and Ignacio Zaragoza. It is unable to make explanation concerning the reason of the difference of character of these ores, because details of geology inside of the adits are yet unknown. Ores

composed of magnetite and sulfide minerals are qualitatively similar to those of the Encarnación mine, but the ores here are much more rich in cupriferous minerals, such as, mainly bornite and chalcopyrite, and subordinately covellite, chalcocite, azurite and malachite. Bornite and chalcopyrite fill paragenetically the interspaces of euhedral magnetite grains, but in some samples irregular-shaped fine grains of chalcopyrite are arranged like a dotted line along the crystal plane of bornite. In a sample probably derived from the Santa Eleanora adit, minute grains of native gold are scattered among magnetite grains. Primary minerals in the magnetite-free ores are bornite, chalcopyrite, pyrrhotite, pyrite and a small quantity of sphalerite. Percentage ratio of contained minerals is variable according to the locality of ore, but in any case, those minerals are crystallized in the interspace of the gauge minerals such as garnet, epidote, etc. Two kinds of ore mentioned above are suffered from secondary replacement as same as those of the Encarnación mine.

Ores from the San Miguel mine, Pechuga   Ores are mostly composed of galena and sphalerite irregularily interlocked in paragenetic form. Chalcopyrite and pyrite are subordinates. Scarcely it is able to find out a kind of argentiferous mineral similar to freibergite. In many cases chalcopyrite is found in the crystals of sphalerite as minute inclusions. Agentiferous minerals are also recognized in galena as minute inclusions showing yellow greenish gray color and isotropism. Quantitative analyses by EPMA shows the values of Ag:19.62%, Cu:23.31%, Fe:2.91%, Zn:2.48%, Pb:2.19%, Sb:27.7%, As:1.14% and S:21.76%. These values are slightly different from those of freibergite, but it became

clear that the mineral is a sulfosalt which resembles to freibergite.

Ores from the Lomo de Toro mine, Zimapán   Ores are mostly composed of galena and sphalerite irregularily interlocked in paragenetic form. Subordinate minerlas are chalcopyrite, pyrite, pyrrhotite and marcasite. Sphalerite and galena are crystallized interspacing the grains of gangue mineral supposed to be calcite containing manganese component. Chalcopyrite is observable intersticially among sphalerite and galena or in these two crystals. Pyrrhotite is accompanied with idiomorphic pyrite in many cases and replaced by marcasite. In this case, marcasite encircles the irregular shaped remnants of pyrrhotite or chalcopyrite in the center. In some parts, marcasite is present as inclusions in galena suggesting that marcasite replaced the preexisted pyrrhotite.

Ores from the María Antonietta Mine, Zimapán   Ores mainly composed of sphalerite and galena interlocked paragenetically. Subordinates are chalcopyrite, antimony mineral (stibnite?) and silver minerals. Antimonious mineral mostly surrounds the grains of galena and sphalerite showing an amorphous colloform banding. Partly are also observed fine needles of antimonious mineral. Argentiferous minerals coexist paragenetically with galena and sphalerite. There are two varieties of argentiferous minerals in this mine. One shows yellow greenish gray reflection color and isotropism resembling to freibergite, and the other pale yellowish green reflection color and weak anisotropism. The results of the quantitative analyses by EMPA on two grains which belong to the first variety are as follows:

Ag	Cu	Fe	Zn	Sb	As	S	in weight percent
21.00	16.35	3.48	3.06	27.10	2.88	20.84	
32.10	14.83	5.89	-	23.10	6.98	19.66	

The results confirmes that the mineral is a sulfosalt which resembles freibergite. The vlaue obtained by the same analyses for the mineral of another variety is as follows:

Ag: 64.80, Sb: 16.91, As: 4.67, S: 17.39 in weight percent. Molecular formula tentatively calculated from these values is $Ag_{3.32}$ $(Sb, As)_{1.11}$ $S_{3.00}$, and quite resembles the formula of pyrargyrite (Ag_3SbS_3).

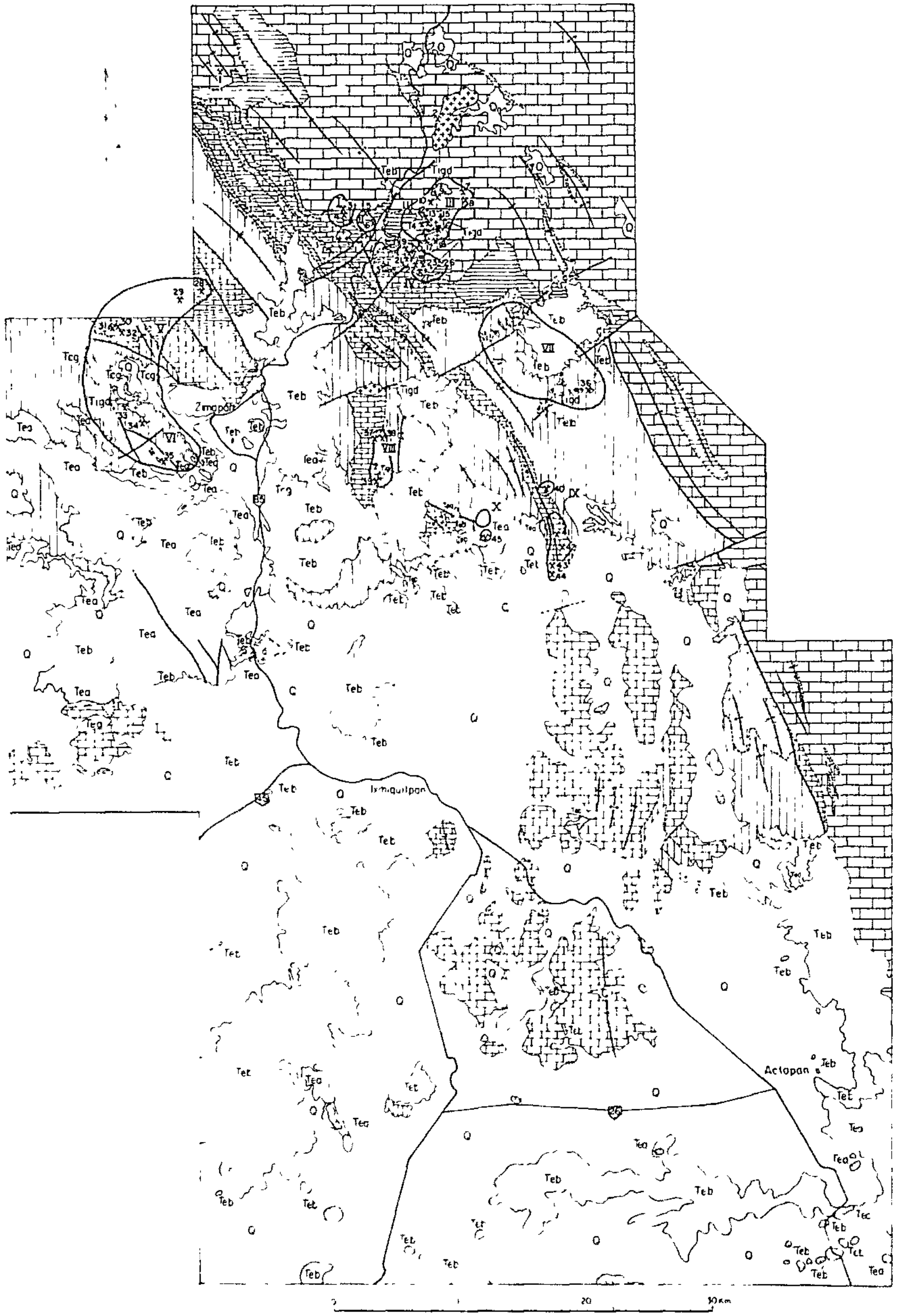


Fig. IV-7 Location of Metal Mine in the Survey District

No	Mineralized zone		Mine or Showing
		1	San Francisco
		2	Nameless
I	San Antonio - La Luz	3	San Antonio
		4	La Luz
II	Dos de El Aguila	5	Dos de El Aguila E
		6	Dos de El Aguila W
III	Encarnación	7	Delicias
		8	Santa Domingo
		9	Nameless
		10	El Cambio
		11	Corral Viejo
		12	La Cueva del Tejon
		13	Santo Tomás
		14	Dulces Nombres
		15	Aguila Roja
		16	San Francisco
		17	Rigel
		18	Socorro
IV	El Zapote	19	El Conejo
		20	Nameless
		21	Ignacio Zaragoza
		22	San José del Oro
		23	Carcus
		24	Santa Eleanora
		25	La Trinidad
		26	Concordia
		27	Los Gallos
V	Zimapān	28	San Francisca
		29	San Miguel
		30	Los Balcones
		31	La Prisima Fresnillo
		32	Loma de Toro
VI	South Zimapān	33	Maria Antonietta
		34	Guadalupe
		35	Nameless
VII	Poterero	36	Nameless
VIII	Pechuga	37	Santa Elena
		38	Santa Elena
		39	San Miguel
IX	Yonthe - San Joaquin	40	Providencia
		41	San Joaquin
		42	San Vicente
		43	Los Aminas
		44	San Bernardo
X	San Clemente	45	San Clemente

CHAPTER V

SUMMARY AND CONCLUSIONS

V-1 Summary

The investigation in 1979, the first step of the project, includes the works of the three kinds, namely, preparation of the topographic maps of the whole area, photogeological interpretation and geological field work. The emphasis in these works was put on elucidation of general geology and structure of the whole district, and on the description of each mineral deposit. Concretely, the main purpose of the investigation was the delineation of promising areas for the development of mineral deposit which will be the main target of the works in the year 1980, second phase of the project.

Through the investigation, lots of important data concerning on geology, structure, igneous activity, mineralization and mutual relationship of them, were obtained and plenty of the essential facts became clear, however, some problems were still left behind expecting to find the solution in the detailed study of the coming year.

Conclusions of the present-phase investigation and problems left to the next year are summarized as follows:

[Stratigraphy of the Cretaceous System]

Cretaceous system distributed in the northern half of the district is composed of the massive limestone formation, flint-alternated formation, and shale formation comformably accumulated in ascending order. In the southern half and the western central parts, the *Hippurites* reef limestone formation, which seems to be a contemporaneous heterotopic

facies of the flint-alternated formation, dominates and the shale formation conformably overlies.

Sedimentary rocks involved in the Cretaceous system are severely folded and locally show an overturned succession by the effects of the Laramide orogeny , although the grade of the effects is variable in each formation. Generally, the strike of strata is in NW and inclination is to SW.

The time of sedimentation of those formation is concluded as follows according to the identified age of macro- and micro-fossils collected from those formations: The age of the massive limestone formation is between early Cretaceous and Cenomanian stage of late Cretaceous. The flint-alternated formation and *Hippurites* reef limestone formation are of late Turonian stage, and the shale formation is of the age between late Turonian and Maestrichtian stages.

These conclusions concerning on the time of sedimentation do not coincide partly with the results described in the previous work (Segerstrom, 1962). The discordance between those two is probably due to the difference of collected fossil samples, and the solution of the problem is expected by the detailed study on the macro-fossils and nannofossils in the coming phase of the investigation.

[Tertiary and Quaternary Systems]

Tertiary system distributed in the district is mainly composed of volcanic rocks and is associated with locally distributed basal conglomerate. The time of eruption of almost all volcanic rocks is

involved in the period from 38.1±1.9 m.y. to 26.5±1.3 m.y., according to the K-Ar age determination.

Accordingly, igneous activity in the district is supposed to have been quite active during the time of Oligocene. Lithologically, lava flows and volcanic breccia of andesitic and basaltic nature are dominant in the time from early Oligocene to the first half of late Oligocene, and rhyolitic lava and tuff which erupted in the second half of late Oligocene are locally distributed. Additionally, basaltic lava which erupted probably in Miocene and Quaternary volcanics are locally observable.

[Geologic structure]

Characteristics of the structure in the district are folds and faults observed in the Cretaceous system. These features have been generated by the Laramide orogeny. Tertiary system is undisturbed in appearance and has no evidence of tectonic movement as a whole, although gently inclined strata and some small-scale faults are locally recognized.

Generally speaking, the trend of fold axes in the Cretaceous strata is mostly in NW-SE, and the inclination of the axial plane is in SW. Locally, fold axes bear the evidence of flexure caused by the Tertiary igneous activity. There can be recognized two types of fault system in the district. One is in the direction parallel to the fold axis and another is perpendicular to the former, NE-SW to E-W in direction, namely transverse fault. Characteristics of these faults are that the former belonging to strike fault, has rather large perpendicular throw and the

latter belonging to transverse fault has generally a small throw and is accompanied by horizontal slip. The transverse fault which is considered to extend latitudinally at the central part of the survey district, is covered by the Quaternary sediments and unable to study in detail. However, it is presumable that the estimated transverse fault reflects the fault which has already existed in the basemental rocks of the district. The reasons of the presumption are two. One is the fact that the difference of sedimentary environment shown by the existence of contemporaneous heterotopic facies is observable in some parts of the Cretaceous strata distributed in the northern and southern halves of the district placing that fault in between. The other is the fact that the intrusive masses seem to occurr roughly arranging along the direction of that fault.

[Intrusive rocks and mineralization]

Intrusive rocks occurred in the district are granodioritic rocks, andesitic and rhyolitic rocks. Among them, andesitic and rhyolitic rocks are locally distributed as small-scale dykes. On the other hand, granodioritic rocks are considered to be important because the rocks occur on a large scale and have intimate relation to the genesis of ore deposits.

Granodioritic rocks intrude the Cretaceous strata in the northern half of the survey district and seem to be aligned in two trends, namely, in the directions of NW-SE and NE-SW. These trends coincide with those of main fault systems in the district. The time of intrusion of the

masses located near Encarnación and in the west of San Nicolás is determined by K-Ar dating as 50.9±2.5 m.y. and 40.5±2.0 m.y., respectively, that is to say, in Eocene.

At the contact of the intrusive rocks and the Cretaceous limestones, pyrometasomatic iron-copper ore deposits accompanying gold and silver are generated. In the recrystallized limestones located around the intrusive rocks, hydrothermal manto- or chimney-type lead and zinc ore deposits accompanying gold and silver are scatterd. As here mentioned, intrusive rocks have intimate relation to mineralization and are distributed roughly in two definite trends. Because of these reasons, behavior of the intrusive rocks is considered to serve extremely on the selection of promising areas hereafter.

An important ore deposit located in the district is a gold deposit in the potash rhyolite lave dome unusually rich in potassium. Being rather different from normal gold deposit, the deposit is of dissemination type in fresh rock, not of vein type. As a whole, host rock seems to be fresh, but partly argillized and have neither quartz vein nor silicified zone. The rhyolite occupies the area of 2.5 km × 5 km. In the present phase of investigation, rock samples were collected from several points along a line extending 2.5 km in latitudinal direction at the southern part of the rhyolite body. Contents of gold and silver in those samples are extremely higher than the contents as primary dispersion in the ordinary rhyolite, suggesting that the activity of the rhyolite and gold-silver mineralization are intimately linked together. Because of the reason mentioned above, it is concluded that the systematic investigation of the

geochemical behavior of gold, silver and other components in the whole rhyolitic body is quite necessary.

V-2 Conclusions

Based on the above-mentioned results of the investigation carried out in the year 1979 as the first phase of the project, survey area and method of study in and after the second phase of the project will be recommended as follows (Ref. Fig. V-1):

1. Following area should be studied using the methods mentioned below.

   Area: An area of 850 km^2 which is quite promising for mineralization. The area involves all mineralized zones and also intrusive rocks which have intimate relation to mineralization or have strong possibility to relate.

   Method: Suitable accuracy of each survey will be semi-detail.

   i) Geological mapping ..... Completion of the geological map Scale 1:25,000

   ii) Geochemical exploration ..... Object: Stream sediments Indicator elements: Ag, Pb and Cu

   iii) Surface magnetic survey ..... At the suitable points on the route of geological survey.

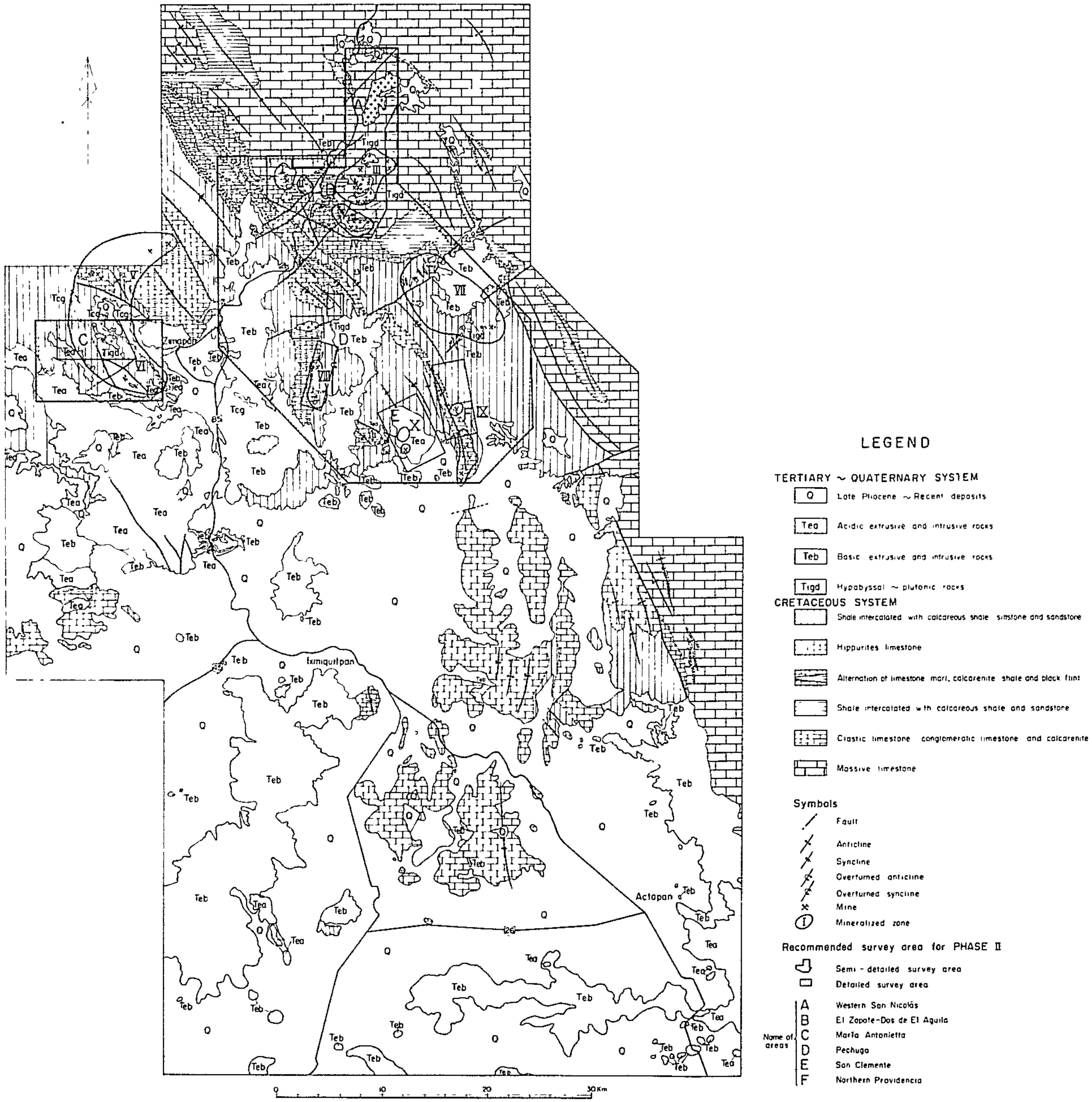


Fig. V-1 Recommendation Map

2. Detailed survey on the areas mentioned below.

	Name of area	Dimensions (km^2)	Contents of survey
A	Western San Nicolás	28	Detailed geological survey and detailed geochemical exploration (soil samples, indicator elements: Ag, Pb and Cu)
B	El Zapote-Dos de El Aguila	67	In addition to the detailed surveys in area (A), electric survey using I.P. method around the Dos de El Aguila mine; 40 line-km.
C	María Antonietta	23	Detailed geological survey and detailed geochemical exploration (soil samples, indicator elements: Ag, Pb and Cu).
D	Pechuga	21	Ditto
E	San Clemente	24	Detailed geological survey and detailed geochemical exploration (rock samples and stream sediments: indicator elements; Au, Ag, Pb, Cu,K_2O and other rock-forming elements).
F	Northern Providencia	21	Detailed geological survey and detailed geochemical exploration (soil samples, indicator elements: Ag, Pb and Cu).
	Total 180 km^2		

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