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THE GEOLOGY OF THE TOPIA MINING DISTRICT, TOPIA, DURANGO, MEXICO

by
John Lemish

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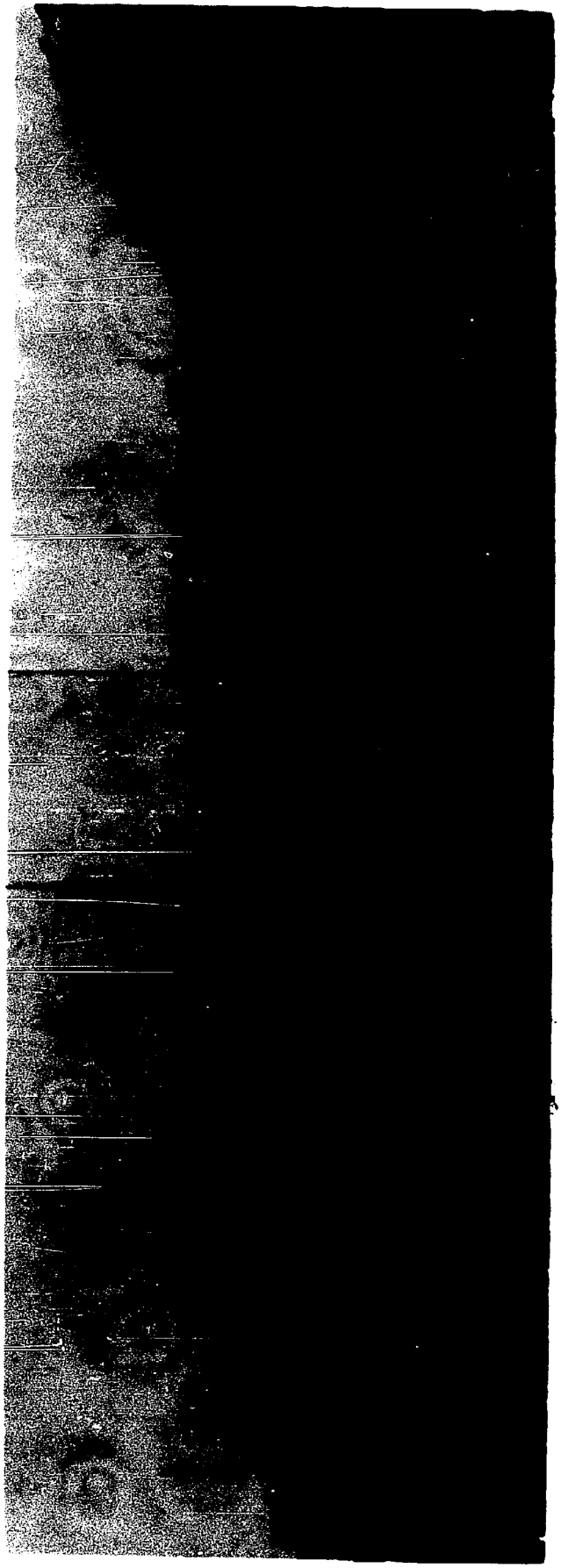
Figure 1--Frontispiece. Panorama of the north side of Rio Topia canyon and main part of the mining district. Looking west from the rhyolite cliffs at the eastern edge of the district. The town of Topia is in the lower left corner on the well developed intermediate erosion surface.



Abstract

THE GEOLOGY OF THE TOPIA MINING DISTRICT,
TOPIA, DURANGO, MEXICO

by John Lemish

Topia is an old 16th century silver district in northwest Durango in which mining has recently been renewed. An estimated $10,000,000 to $20,000,000 in silver was produced mostly between 1870 and 1912. The district is in the canyon country of the Sierra Madre Occidental range which is a partially dissected volcanic plateau. At Topia and in most of the central Sierra Madre, only extrusive rocks are exposed. These can be divided into andesites and rhyolites. Late Cretaceous(?)-early Tertiary andesites of great thickness are unconformably overlain by Miocene(?) rhyolites as much as 600 meters thick. Mineralization is restricted to the andesites and related to a pre-rhyolite granodiorite stock.

Faults of different ages having northwest and northeast trends are major structural features. Three sets are recognized: (1) the major northwest set, (2) the N.60°E. set of vein fissures and faults, (3) the minor set of N.20°E. faults. The northwest and N.60°E. sets form the dominant early-age fault pattern controlling intrusive activity and mineralization. The veins and rhyolites are offset by later normal faulting that occurred along earlier trends and also formed the N.20°E. set.

Three types of hydrothermal alteration occur in the andesites: the regional propylitic, local propylitic, and quartz-sericite types.

The regional and local propylitic types, essentially similar but of different age, are green-colored rocks rich in chloritic minerals. The regional type surrounding the granodiorite stock in the southwest part of the district is a widespread pervasive alteration in which three mineral assemblages were recognized and interpreted as an intensity zoning outward from the granodiorite. The assemblages in order of decreasing intensity are: (1) albite-chlorite-epidote, (2) albite-chlorite-epidote-calcite, (3) albite-chlorite-calcite. The local propylitic type characterized by an albite-chlorite-calcite assemblage forms bands up to 25 meters wide bordering every vein in the fresh andesites of the main district beyond the regional propylitic zone. The quartz-sericite type forms a narrow 30 to 60 centimeter band of grayish rock composed of abundant quartz and sericite located between the vein and propylitized andesite. The quartz-sericite type represents a more intense alteration related to the veins and superimposed on local or regional propylitization.

The ore deposits, mined primarily for silver and minor amounts of lead and zinc, occur in nine main parallel veins averaging 30 centimeters in width. They strike N.60°E. and dip 80°S. Over 40 minor veins of similar attitude are present. The major veins, one of which is 5 kilometers long, are persistent features occupying fault fissures considered to be shears. Ore shoots extend over long distances along strike but probably not to great depth although sulphide minerals are present throughout a composite vertical range of 1000

meters. Arsenopyrite, pyrite, sphalerite, and galena were deposited in that order largely by open filling. Freibergite, chalcopyrite, and ruby silver minerals were deposited somewhat later by replacement. Quartz of many generations and some late barite and calcite form the gangue. The deposits are classed as leptothermal.

Alteration and ore deposition are related to the same period of hydrothermal activity. The regional propylitization is definitely hydrothermal and not deuteric in origin. It is interpreted as a widespread, early, barren type of alteration caused by alkaline solutions rich in carbon dioxide producing intensity zones about the granodiorite as temperature decreased. A break, probably structural, occurred after this initial barren phase. Later more intense solutions caused local propylitization, quartz-sericite alteration, and vein mineralization along fissures in fresh rocks; the solutions superimposed quartz-sericite alteration and vein mineralization on pre-existing regionally propylitized andesites.

TABLE OF CONTENTS

	Page
ILLUSTRATIONS	viii
Chapter	
I. INTRODUCTION	1
Geography	3
Location and Accessibility	3
Regional Setting	3
History of Mining	7
Field Work	9
Acknowledgments	9
II. GENERAL GEOLOGY	11
General Statement	11
Regional Geology	12
Nature of the Extrusive Rocks	17
Topia Andesite	18
General Features	18
Santa Ana Member	25
Carmen Member	25
Los Hornos Member	26
Undifferentiated Tuff	27
Petrography	28
Deuteric Alteration	29
Age and Correlation	30
Quartz Monzonite	31
Granodiorite Stock	35
Distribution	35
Petrography	35
Contact Metamorphism	36
Age and Correlation	37
Quartz Latite Dike	38
Rhyolite Dikes	39
Petrography	42
Age	43
Diabase Dikes and Pebble Dikes	43
Distribution	43
Petrography	44
Age	45
Rhyolite Volcanics	46
Distribution	46
Lithology	49
Age and Correlation	51
Tertiary-Quaternary Gravels	52
Structure	53

Page

General Statement 53
Local Structure 55
Northwest Faults 55
N.60°E. Fissures and Faults 59
N.20°E. Faults 61
Origin of the Faulting 61
Unconformity between the Topia Andesite and Rhyolite Volcanics 63
Geomorphology 65
General Features 65
Erosion Surfaces and Canyon Development . 68
Drainage Pattern 73
Local Pattern 73
Regional Pattern 73
Geologic History 74

III. HYDROTHERMAL ALTERATION 77

Introduction 77
Nature of the Alteration 77
Types of Alteration 79
Method of Investigation 81
Mineralogy of the Altered Rocks 82
General Features 82
The Alteration Minerals 83
Chlorite Group and Related Minerals . 83
Albite 87
Calcite 88
Epidote 88
Sericite-Hydromica 89
Quartz 89
Pyrite 90
Accessory Minerals 91
Description of the Altered Rocks 93
Regional Propylitic Type 93
General Features 93
Distribution 94
General Description 97
Petrographic Description 98
Intensity Zoning 102
Relation to Ore Deposits 104
Local Propylitic Alteration 104
Distribution 105
Petrographic Description 105
Relation to Ore Deposits 113
Quartz-Sericite Type 114
General Features 114
Distribution and Controls 114
Petrographic Description 115
Chemical and Physical Changes 118
Details of the Study 118
Changes in the Local Propylitic and Quartz-Sericite Types 120

Page

Physical Changes 120
Chemical Changes 121
Changes in the Regional Propylitic Type . 125

IV. ORE DEPOSITS 128

General Statement 128
Description of the Veins 129
Distribution 129
Structural Details of the Veins 132
Attitude of the Veins 132
Pre-Mineral Faults and Fissures . . . 132
Minor Branching Veins 136
Cymoid Structure 137
Post-Mineral Faults 137
Vein Texture 142
Ore Shoots 149
Structural Controls 150
Wall Rock Control 151
Changes with Depth 152
Structural History and Age of the Veins . 156
Vein Mineralogy 157
Vein Minerals 157
Arsenopyrite 158
Pyrite 158
Galena 159
Sphalerite 159
Argentian Tetrahedrite (Freibergite) . 160
Chalcopyrite 161
Ruby Silver Minerals 161
Gold 162
Native Silver 162
Chalcocite and Covellite 162
Quartz 163
Barite 163
Calcite 163
Supergene Gangue Minerals 164
Paragenesis 164
Mineral Zoning 175

V. ORIGIN OF THE ALTERED ROCKS AND ORE DEPOSITS . 178

Introduction 178
The Problem of Propylitic Alteration 178
Definition 178
Origin 179
Evidence for the Hydrothermal Nature of the Alteration at Topia 184
Factors Influencing Hydrothermal Activity at Topia 185
Nature of the Hydrothermal Solutions 188
The Alteration Sequence 188

Page

Propylitic Alteration 191
Quartz-Sericite Alteration 194
Ore Deposition 197
Summary 198
Source of the Solutions 199
Classification of the Deposits 201

BIBLIOGRAPHY 202

ILLUSTRATIONS

Figure		Page
1.	Frontispiece. Panorama of the north side of Rio Topia Canyon and main part of the mining district	iii
2.	Index map of Mexico showing area covered by regional index map	2
3.	Regional index map showing location of Topia with respect to the Barranca and Plateau sections of the Sierra Madre Occidental province	5
4.	Composite diagram of the Topia Andesite	21
5.	The sequence of the Topia Andesite	22
6.	Bedding features in the pyroclastic material of the Santa Ana tuff unit in the vicinity of the Tres Varones mine	24
7.	Pebble dike (left) and diabase dike (right) cutting andesite tuffs west of the Tres Varones mine	24
8A.	Andesite tuff from diamond drill hole 350 meters east of Topia	33
8B.	Same as 8A	33
9.	Andesite lava from the mine dump at the Socavon Victoria	33
10.	Quartz monzonite prophyry from Tres Varones creek	33
11.	Granodiorite from Rio Topia Canyon 6 kilometers southwest of Topia	41
12.	Contact metamorphosed andesite lava from Rio Topia Canyon 5 kilometers southwest of Topia	41
13.	Quartz latite from dike in Rio Topia Canyon at Molinos	41
14.	Rhyolite from dike in Rio Topia Canyon 2 kilometers southwest of Topia	41

Figure

Page

15A. Pebble dike material from pebble dike on Caneles trail 200 meters south of Topia 48

15B. Same as 15A 48

16. Diabase from dike 1 1/4 kilometers west of Topia 48

17. Rhyolite tuff from cliff 1 1/2 kilometers north of Topia 48

18. View of the north side of Rio Topia Canyon showing the unconformable relationship of the horizontal rhyolites and the tilted andesites 67

19. Looking at the northeast side of Rio Topia Canyon where the broad sloping intermediate surface is being dissected by stream erosion to form the inner gorge 67

20. Profile across canyon of Rio Topia 71

21. Idealized profiles illustrating the successive stages in the cutting of Rio Topia Canyon 72

22. Looking southwest down the canyon of Rio Topia at the highly dissected topography of the barranca section 95

23A. Andesite tuff, low intensity regional propylitic alteration, from locality 1 1/4 kilometers southwest of Topia 101

23B. Same as 23A 101

24. Andesite lava, low intensity regional propylitic alteration from Los Hornos Ridge 1 1/4 kilometers south of Topia 101

25. Andesite lava, moderate intensity regional propylitic alteration from Rio Topia Canyon 2 1/2 kilometers southwest of Topia 101

26. Andesite lava, high intensity regional propylitic alteration from bottom of Rio Topia Canyon 3 kilometers southwest of Topia 107

27. Andesite lava, high intensity regional propylitic alteration from the bottom of Rio Topia Canyon 3 kilometers southwest of Topia 107

28. Andesite lava, 5 meters south of Cantaranas vein, San Miguel mine 107

Figure Page

29. Andesite lava, 2 meters south of Cantaranas vein, San Miguel mine 107

30. Andesite lava, 65 centimeters south of the Cantaranas vein, San Miguel mine 109

31. Andesite lava, adjacent to south side of the Cantaranas vein, San Miguel mine 109

32. Andesite lava, adjacent to Las Animas vein, Olivia mine 109

33. Chemical and physical changes adjacent to a vein 122

34. Geologic map of the La Perla vein on Tepalcates ridge showing the surface details of the La Perla vein, alteration zone, and orientation of forces 135

35. Plan showing the branching of the La Perla vein with the change in strike to form a cymoid loop . 138

36. Plan showing the branching of the Las Animas vein coinciding with the change in strike to form a cymoid loop 139

37. Plan of the San Miguel mine showing several post-mineral faults 140

38. Specimens of the Cantaranas vein from the San Miguel mine showing the typical banding seen in many of the veins 145

39. "Raisin" or "Spotted" texture seen in specimen from the San Miguel mine 145

40. Specimens of silicified breccia from the Trinidada and La Perla veins 148

41. Several specimens of silicified and mineralized breccia from the Las Animas vein at the Olivia mine 148

42. Longitudinal sections of old mine workings showing the relationship of ore shoots and wall rock . . 153

43. Graphic representation of the mineral sequence at Topia 166

44. Arsenopyrite (a) replaced by galena (g) in a specimen from the La Perla vein, Tres Varones mine 169

Figure Page

45. Arsenopyrite (a)-pyrite (p) relationship in a specimen from the Las Animas vein, San Felipe mine 169

46. Pyrite (p) replaced by galena (g) in a specimen from the La Perla vein, Tres Varones mine 169

47. Galena (g)-sphalerite (s)-pyrite (p) relationship in a specimen from the Las Animas vein, San Felipe mine 169

48. Freibergite (f) replaces galena (g) and sphalerite (s) in a specimen from the Cantaranas vein, San Miguel mine 172

49. Ruby silver (r) cuts freibergite (f) and galena (g) in a specimen from the Cantaranas vein, San Miguel mine 172

50. Ruby silver (r) replaces galena (g) in a specimen from the Cantaranas vein, San Miguel mine 172

51. Ruby silver (r) cuts chalcopyrite (cp) and freibergite (f) in a specimen from the Amarilla vein, Amarilla mine 174

52. Supergene covellite and chalcopyrite in a specimen from the Las Animas vein, Olivia mine 174

Plate

I. Geologic map of the Topia mining district . . in pocket

II. Geologic structure sections of the Topia mining district . . . . . .in pocket

III. Structure and alteration map of the Topia mining district . . . . . .in pocket

Table

1. Optical properties of chloritic and related minerals in altered andesites, Topia, Durango, Mexico 85

2. A comparison of fresh and propylitized andesites 126

CHAPTER I

INTRODUCTION

Topia is one of the old mining camps of Mexico once noted for its rich silver veins. The district has been dormant for the last 40 years until renewed mining of silver, lead, and zinc ores was recently initiated.

This study is one of the first detailed geological investigations of a mining district located in the canyon country of the Sierra Madre Occidental, a region that is little known, and except for the work of R. E. King (1939) and a few others, an unknown region to many geologists. The fields of major interest emphasized are the petrology, structure, hydrothermal alteration, and the ore deposits. The thick sequence of volcanic rocks was divided into mappable units to work out the structural relationships of the district. The geological setting made it possible to undertake a detailed study of propylitic alteration and its relation to the ore deposits.

This investigation was made under the auspices of the Compania Minera de Peñoles as part of its student program in which various Mexican areas of interest to the company have been studied. The main purpose of this study was to obtain a better understanding of the economic possibilities of Topia.



FIG. 2 Index map of Mexico showing area covered by regional index map.

GEOGRAPHY

Location and Accessibility

The Topia mining district surrounds the town of Topia in the northwest corner of the state of Durango and in the political subdivision called the Partido de Tamazula. It lies at 25°11'N. lat. and 106°33'W. long. on the western slope of the Sierra Madre Occidental (Fig. 2). Although Topia is only 140 kilometers (87 miles) from the Pacific coast and 100 kilometers (60 miles) east of Culiacan, Sinaloa, the extremely rough topography and deep canyons of the western slope make communication and transportation with the west coast so difficult that the area is economically dependent on the interior regions of Mexico. From Tepehuanes, the terminal of the railroad extending 210 kilometers (130 miles) north from the city of Durango, the mining district can be reached over a truck road of 160 kilometers (73 miles) which crosses the Sierra Madre Occidental (Fig. 3). Until this road was completed by the Compañia Minera de Peñoles in January 1952, all transportation was dependent on pack animals.

At present (1955) Topia is a town of about 500 inhabitants and is the largest settlement in this sparsely settled region.

Regional Setting

The Sierra Madre Occidental, one of the least known

regions of North America, is part of the western Cordillera, a chain of mountains that parallels the Pacific coast and extends into Central America. The northern part of the Cordillera, within which Topia is located, is essentially a broad, rolling and partly dissected volcanic plateau that extends from southern Sinaloa and Durango north-northwest into northern Sonora immediately south of the United States border. Brand (1937, p. 11) named the plateau the Sierra Madre Occidental physiographic province and described it as:

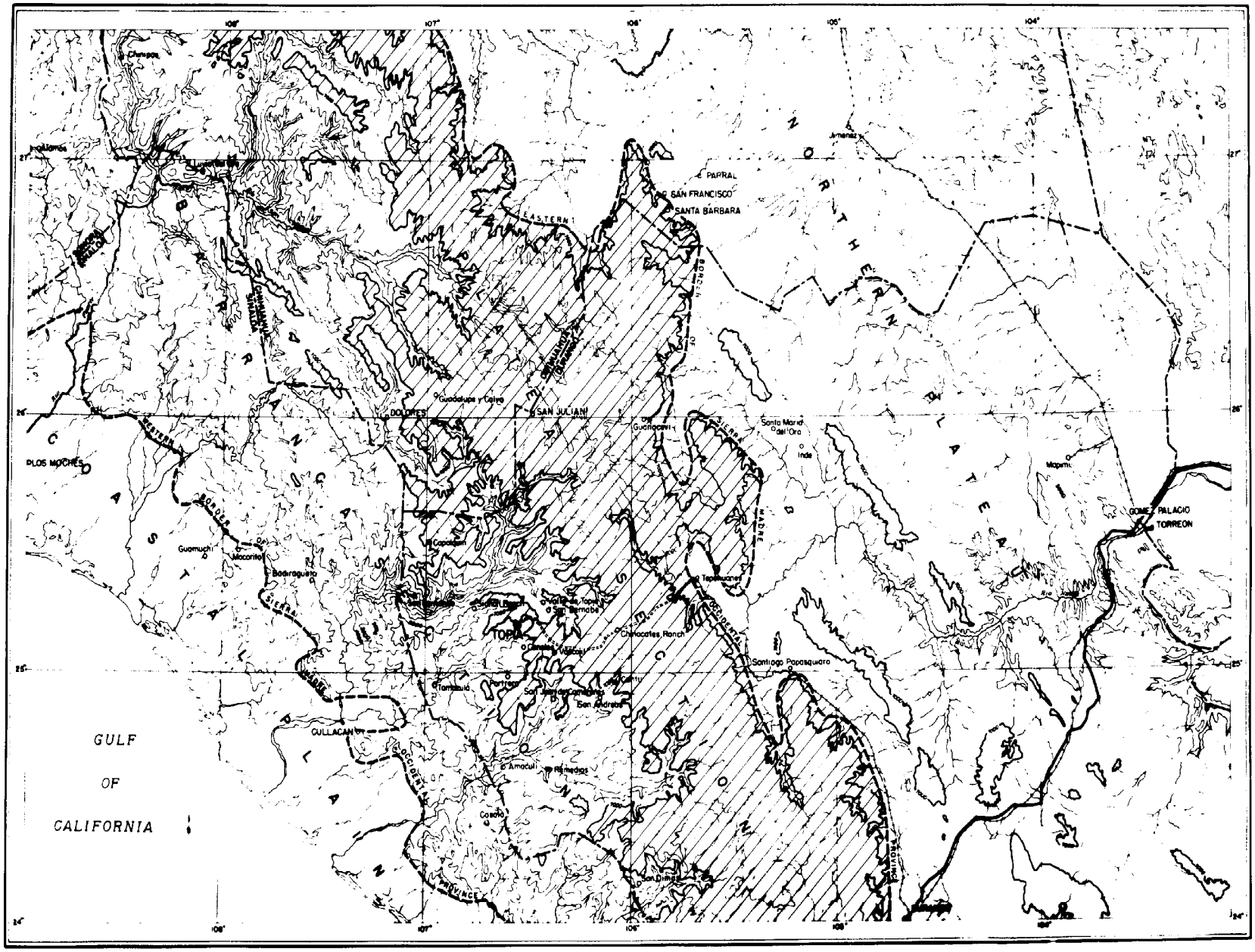
> "...a great plateau of extrusives, having NNW-SSE narrow structural depressions between smooth-topped ridges, mesas, and minor plateaus, and segmented by the gorges of transverse antecedent or headward eroding streams flowing through deep gorges to the Pacific lowlands."

The province is bordered on the west by the Pacific coastal plain, on the east by the Mesa del Norte, and on the south by the Mesa Central.

R. E. King (1939, p. 1632) divided the northern part of the province into the plateau section and the "barranca" or canyon section. He describes the barranca section as:

> "...a belt of deeply dissected country 25 to 60 miles wide...composed for the most part of gently tilted lava flows, but streams, which flow southward to the Gulf of California. have developed a youthful topography. A few remnants of flat ground on the high interstream divides give proof of the former extension westward of the mature surface which is still unbroken in the plateau to the east. The major southwest-flowing streams, as a result of the general down-cutting of the area, have carved out tremendous barrancas some of which reach 6000 feet in depth. Since these are the most characteristic features of this belt of country, the area is here termed the 'barranca section'."

On the basis of King's subdivision of the province, a



Contour interval 1000 ft

FIG 3 Regional index map showing location of Topia with respect to the Barranca and Plateau sections of the Sierra Madre Occidental Province Plateau section shown by the ruled pattern

regional map has been prepared, and the plateau and barranca sections have been extended southward to include the Topia area (Fig. 3).

The plateau section on the east is essentially that portion of the province that has not yet been dissected by the Pacific drainage. The section is characterized by gently rolling and hilly topography that represents a mature erosion surface carved in Tertiary rhyolites. The average elevation of the plateau is about 2000 meters (7000 feet) but some areas rise to 3000 meters (10,000 feet). The entire plateau, heavily covered by pine and hardwoods, includes one of the last great timber reserves of North America

Far-reaching canyons of the barranca section have formed an extremely irregular border with the plateau section and have created a series of isolated plateau remnants. Where the plateau rhyolites have been stripped off, the older andesites have been dissected into a series of ridges and gorges characteristic of the barranca country (Fig. 22). On extensions of some of the interstream divides, the overlying rhyolites form precipitous cliffs, some of which exceed 600 meters (2000 feet) in height. Topia, situated on the andesite formation in the upper portion of one of the far-reaching barrancas, is surrounded on three sides by such cliffs (Fig. 1, Frontispiece). The canyon at Topia reaches a depth of 1200 to 1500 meters (4000 to 5000 feet).

The region has a pronounced rainy season from

mid-June through early October and a dry season for the rest of the year. Records kept by the Compania Minera de Peñoles at Topia over a three-year period show that the annual precipitation is from 30 to 40 inches, with most of it occurring in the summer months. The precipitation decreases progressively to the east until the areas east of the Sierra Madre barrier are dry most of the year.

Because of the great relief in the canyons, the temperature in the vicinity of Topia is variable. The deeper portions of the canyons are tropically hot and humid during the rainy season, whereas the plateau is fairly cool. Although during the dry winter months the plateau has frosts and occasionally a little snow, the temperature at Topia and at lower elevations is mild.

The vegetation is highly varied because of the unusual relief of the area. On the plateau surface pine forests prevail; at intermediate elevations hardwoods, shrubs, and various fruit trees are present; and in the deep canyons tropical plants such as bamboo, bananas, and mangoes abound.

HISTORY OF MINING

Mining activity in the Topia district dates back to the very early history of Mexico. Although the area is reported to have been explored in 1538 during Coronado's pacification of the west coast, the earliest record of mining activity is in 1602 (Espinosa, 1628, p. 192). The

existence of mines in 1602 shows the original discovery of the district to have been at an even earlier date. Very little is known about the 17th and 18th century history of Topia, although it is believed that some small scale mining took place during that time.

Topia reached its peak of development in the period from 1870 to 1910, with five companies under American, German or Mexican control in operation concurrently during this period of maximum production. High-grade silver ore and silver bullion were packed to the interior of Mexico or to the west coast for shipment abroad. The city of Topia, much larger than at present, is said to have had a population of over 2000.

The decline of Topia after 1912 was not due primarily to the exhaustion of the ore reserves. The unrest and instability of the revolutionary times was a major cause, as well as the ascendancy of Pachuca and other mining camps which began large scale operations about 1915. World War I may have been another cause, when the German owners lost control of the mines. The inaccessibility of the district, the higher costs of mining, and the possible lowering in the grade of the ores as the mines deepened may also have contributed to the decline.

Only minor prospecting was carried on by "gambusinos" (prospectors) until 1944 when the Compania Minera de Peñoles of Monterrey became interested in the district as a result of the efforts of Plutarco Alonso of Topia. Since 1944 the district has been under investigation, and mining on

a small scale has recently commenced. A mill to process the ore was completed in 1953. The lead-silver concentrates are now shipped to the company's smelter in Torreon and the zinc concentrate to Blackwell, Oklahoma.

Production records for the district are very fragmentary. Estimates made by those familiar with the camp range from $10,000,000 to $20,000,000, most of the value being in silver. This production was obtained mainly during the period from 1870 to 1912.

FIELD WORK

The field work for the present study extended from June to September of 1951 and from July through August of 1952. Topographic sheets to the scale of 1:2500 and 1:10,000 were utilized in the surface mapping. Complete aerial photographic coverage was available, but the photographs were used only in general investigation and reconnaissance. The accessible mine workings were mapped on a scale of 1:500.

ACKNOWLEDGMENTS

The writer would like to express his gratitude to the Compania Minera de Peñoles of Monterrey, Mexico for the opportunity that made this study possible Also, he is especially indebted to Mr. David B. Dill, Jr. for arranging and directing the investigation and to Mr. F. L. Wingfield, who made the first examination of the district, for his

interest and cooperation. Mr. Plutarco Alonso and Mr. Herman Linden were of great assistance in making local arrangements and their kindness and hospitality are much appreciated. Members of the Topia mining staff who were helpful during the two field seasons are Mr. Tom Berray, the former mine manager, Mr. John Engstrom the present manager, and Mr. Francisco Espinosa. Mr. Pedro Ortega served as field assistant

Professor C. H. Behre, Jr., of Columbia University visited the area and offered many valuable suggestions.

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Mr. Derwin Bell drafted the maps, cross sections, and many of the figures in the text. His expert work and many helpful suggestions concerning the illustrations are gratefully acknowledged.

CHAPTER II

GENERAL GEOLOGY

GENERAL STATEMENT

At Topia and elsewhere throughout the central Sierra Madre Occidental the thick series of extrusive igneous rocks exposed in the deep canyons can be divided into two main groups: the older underlying andesitic rocks of late Cretaceous(?) to early Tertiary age and the younger rhyolitic rocks of Miocene(?) age. The Topia district lies in a window of andesite that is surrounded on three sides by a thick series of flat-lying and cliff-forming rhyolites. A pronounced unconformity separates the unmineralized rhyolites from the older andesites which have been tilted to the southwest at an average dip of 25°. The andesites have been intruded by a granodiorite stock as well as by acid and diabase dikes. Although the total thickness of the andesite group is not known, over 1400 meters (4600 feet) of andesites are exposed in the district.

The main structural features of the area are normal faults of various ages. A distinctive pattern exists in the major northwest-trending faults and the northeast system of fissure veins. Some of the faults cut all the rocks in the district, but the veins are restricted to the andesites.

The deposition of the andesites was followed by a period of faulting, intrusion, and mineralization. Subsequently, there was a long period of erosion after which a thick sequence of rhyolitic rocks was deposited on an irregular andesite surface. The area was faulted, repeatedly, during late Tertiary time when the Sierra Madre range was uplifted into its present plateau-like form. Rejuvenation of the streams at this time initiated a period of canyon-cutting that is still in progress. This has resulted in the development of "barrancas" along the western slope of the range.

REGIONAL GEOLOGY

The Sierra Madre Occidental, which represents a large accumulation of volcanic rocks parallel with the west coast of Mexico, forms a physiographic province which can be divided into two sections: the plateau section along the eastern flank of the range, and the barranca section along the western slope. Topia, although situated within one of the barrancas, is actually on the border between the two sections in the central part of the range. Figure 3 illustrates the two divisions of the province and shows the location of Topia with respect to its regional setting. Both the barranca and plateau sections are well developed in the area, and the irregular border between the two is at an elevation of 7000 feet.

The extrusive rocks of the Sierra Madre Occidental

consist of older andesites overlain unconformably by a thick cover of rhyolitic rocks. The thick series of extrusives lies on a basement complex of Paleozoic and Mesozoic rocks which were severely deformed and even metamorphosed in many places during the Cretaceous(?) and Laramide orogenies. Granitic intrusions and large areas of propylitic alteration are common in the andesites of the deeper parts of the canyons (Santillan, 1929, p. 15; Weed, 1902, p. 446). The region is heavily mineralized and in nearly all cases the deposits are restricted to the older andesitic rocks.

The regional structure of the range as a whole is in many respects similar to that observed at Topia. R. E. King (1939, p. 1699), who made a geological reconnaissance of the northern part of the range, reports strong normal and thrust faulting. He mentions a large fault escarpment along the western front of the range and states that the barranca section is structurally more complex than the eastern plateau section. A strong northwest fault system, which forms the dominant topographic trend of the range, has produced a rectangular drainage pattern (Fig. 3). Although most of the streams have southwesterly courses, some streams have northwest trends in places, thus reflecting the regional structure. A good example of structurally-controlled drainage has been noted 14 kilometers east of Topia where the Valle de Topia River, a tributary of the Sianori, is controlled by a major northwest fault with a displacement of several thousands of feet (D. B. Dill, Jr., personal communication).

From studies of the Topia area it is apparent that the geology is similar to that of the northern part of the range. Northwest faulting occurs throughout the Topia area as it does in the north, and the same unconformity is present separating the two types of extrusive rocks. The accordant erosion surface on the plateau rhyolites is believed to be equivalent in time to the clastic Baucarit formation (King, 1939, p. 1681) which lies unconformably on the rhyolites in the northern part of the range. One difference in the Topia area is the lack of gravels resting on either the unconformity between the rhyolite and andesite or on the accordant erosion surface on the rhyolites. This appears to indicate that the Sierra Madre in the vicinity of Topia was a region of erosion throughout most of Tertiary time and served as a source for the more extensive gravel deposits on the flanks of the range, such as those seen at Tepehuanes, Durango, east of Topia.

Considerable doubt exists as to the age of the volcanic succession in the Sierra Madre Occidental, and this makes it difficult to relate the sequence of events at Topia to the overall regional geology. R. E. King (1939), Garfias and Chapin (1949), and C. Fries, Jr. (personal communication) of the Foreign Branch of the U. S. Geological Survey do not agree on the dating of the extrusive rocks. King considers the rocks to be from late Cretaceous to early Tertiary in age, whereas Garfias and Chapin date the extrusives as Miocene. Fries believes the andesites are early Tertiary (or older) and the rhyolites are most

likely Miocene.

The stratigraphic succession as described by King (1939, p. 1679) for the region north of Topia is as follows: a sequence of late Cretaceous andesites, in places interbedded with Cretaceous limestones, is separated by an unconformity from his early Tertiary volcanics which contain some lower andesites and a considerable thickness of rhyolites. The Pliocene(?) Baucarit formation of clastic origin (considered by King to be the equivalent of the Gila conglomerate of the southwestern United States) lies unconformably on the early Tertiary volcanics.

From King's description of the extrusive succession, it is apparent that the thick rhyolite sequence in the vicinity of Topia is equivalent to the upper acid parts of the early Tertiary volcanics. Weed (1902, p. 446) and Botsford (1911, p. 705) report thick basal andesites overlain unconformably by rhyolites in the area immediately north of Topia; Santillan (1929, p. 15) reports the same succession south of Topia. Similar relations have been observed by the writer in a traverse across the central Sierra Madre Occidental. King mentions the rhyolite-andesite unconformity as being observed by Weed and Botsford and anticipated a reclassification of the extrusive rocks. On the basis of the observed relationship throughout a wide area of the range, a two fold division of the extrusives is adopted in this thesis. The basal andesites, designated Topia andesite, and the overlying rhyolites, designated Rhyolite volcanics, represent the extrusive succession.

Garfias and Chapin (1947, p. 79) state that the extrusive rocks of the Sierra Madre were deposited after the main mid-Miocene orogeny. After a period of erosion in the late Tertiary the gravels of the Baucarit type were deposited unconformably on the volcanic rocks. All of the extrusives of the Sierra Madre are considered mid-Tertiary in age by Garfias and Chapin (1947, p. 81).

Carl Fries, Jr. (personal communication) believes the rhyolites to be of Miocene age and the andesites to be Oligocene or older. The rhyolites, widely distributed throughout Mexico and parts of the southwestern United States, are considered to be of Miocene age because they were cut by strong block faulting in Pliocene time. The occurrence of rhyolite-capped fault blocks and the presence of mid-Pliocene vertebrate fossils in rhyolitic basin gravels indicate an early Pliocene age for the block faulting. In view of the strong tilting and erosion, Fries believes the underlying andesites of the Topia area are no younger than Oligocene, but there is no positive indication as to how much older they are. He states that there is evidence of volcanic activity in late Cretaceous sediments and that volcanism continued into early Tertiary time. Because of the lack of strong folding in the Topia andesite he believes they are most likely of early Tertiary age.

The geologic history of the Topia area as observed from field relations indicates that after the andesites were deposited, faulted, intruded, and mineralized, a long period of erosion occurred, following which the rhyolites

were deposited on the andesite. Post-rhyolite faulting then took place. The dating of events by both King and by Garfias and Chapin does not fit the Topia area. The relationships at Topia and elsewhere in the range favor the interpretation of an early Tertiary age for most of the andesites and a Miocene age for the rhyolites. Since the base of the andesites is not seen, a late Cretaceous(?) early Tertiary age is tentatively adopted for the Topia andesite, and the Rhyolite volcanics are considered to be of Miocene(?) age.

NATURE OF THE EXTRUSIVE ROCKS

In the Topia district the andesites were studied in greater detail than the rhyolites because the ore deposits are found only in the former. The andesites represent a thick series of interbedded lavas and pyroclastics of the same composition. In order to map the structure and geologic details, the andesites were separated into three members because of their recognizable boundaries within the district. The mode of origin was the basis for the division into local stratigraphic units. All andesites which are the result of flows such as lavas and flow breccias, were mapped separately from the rocks of fragmental or pyroclastic origin, such as tuffs, agglomerates, and breccias. The rocks were found to be essentially a series of alternating lava and tuff units which were fairly conformable and could be traced for considerable distances within the area. The

Topia andesite was divided into three local members by grouping together mappable lava or lavas with their overlying tuffs and naming each member after the geographic locality where it is best exposed. The lava units gradually terminate toward the west, forming an interfingering relationship of tuff and lava units, similar in many respects to the rapid lithologic facies changes found in some sedimentary units. Thus it was impossible to trace any andesite member more than a few miles, and the members cannot be correlated over wide areas because of the nature of their deposition. Recognition of the members within the district is essentially dependent on the stratigraphic position. No attempt is made or should be made to extend the local terminology of the andesite members beyond the Topia district. The Topia andesite as a whole, however, forms a thick sequence which is present throughout the Sierra Madre Occidental province.

The Rhyolite volcanics, which were mapped as one thick unit, have a lithology that changes considerably. All variations from true rhyolitic flow rocks to ignimbrites (welded tuffs) and tuffs can be seen in the cliffs surrounding Topia. The lithologic units are conformable over a wide area.

TOPIA ANDESITE

General Features

Both the flow rocks and pyroclastic rocks which

make up the Topia andesite are augite andesites. No extrusive rocks of a different composition are associated with the exposed parts of the formation. However, evidence for the existence of quartz-bearing extrusive rocks and sediments underlying the exposed andesite was found in the form of rhyolite, siltstone, shale, and orthoquartzite pebbles which were brought up from great depth by the diabase dikes and pebble dikes.

The structural features of the pyroclastic units are in many respects similar to those of a typical clastic sediment. Nearly all pyroclastic units show some degree of bedding, indicating that the material had been transported (Fig. 6). In various places, excellent crossbedding, crude graded bedding, and torrential bedding were observed. All units consist of numerous beds showing extreme ranges in sorting from silt-sized fragments to boulders. The agglomerates are commonly interbedded with tuffs. The lithological and textural features of the pyroclastics indicate that the beds are the result of local deposition close to the source. The crossbedding present in the tuffs shows that the initial slope at the time of deposition was to the west and the source area was to the east. All of the beds are poorly consolidated and break down easily into a dark soil, tending to form the gentler slopes on the sides of the canyons. The pyroclastics also acted as incompetent beds during structural deformation.

The flow rocks of the Topia andesite form a series of overlapping lenses of flow breccias and individual flow

units. In places where a thick series of flows is exposed, the contacts between the units are distinct. The flow breccias generally occur at these contacts, and commonly a thin layer of agglomerate or tuff is also found there. Because of the preponderance of flow rocks, the thin interbedded pyroclastic layers are included in the flow rock units. On the whole, the flow rocks resist erosion very well, and as a result they form the steeper slopes and cliffs of the area. The flow rocks tend to shatter and brecciate when structurally deformed. The gradual termination of the lava units to the west also indicates that the source area was to the east.

A composite section which demonstrates the relationships of the andesite stratigraphy is given in Figure 4. The structural cross sections also show the characteristic feature of the stratigraphy, namely the gradual lensing out of the lavas to the southwest with the merging of the overlying and underlying tuff beds (Plate II). It is this lensing nature of rocks that makes it very difficult to extend and correlate the local andesite members beyond the Topia district.

Another feature of the Topia andesite is the general conformity of the rocks as a whole The pyroclastic rocks all show a general southwesterly dip, as do the contacts between flow units. A possible explanation of the conformity of the andesites could be deposition on a fairly smooth surface. Another possibility is that the exposed part of the Topia andesite represents the upper part of a very thick

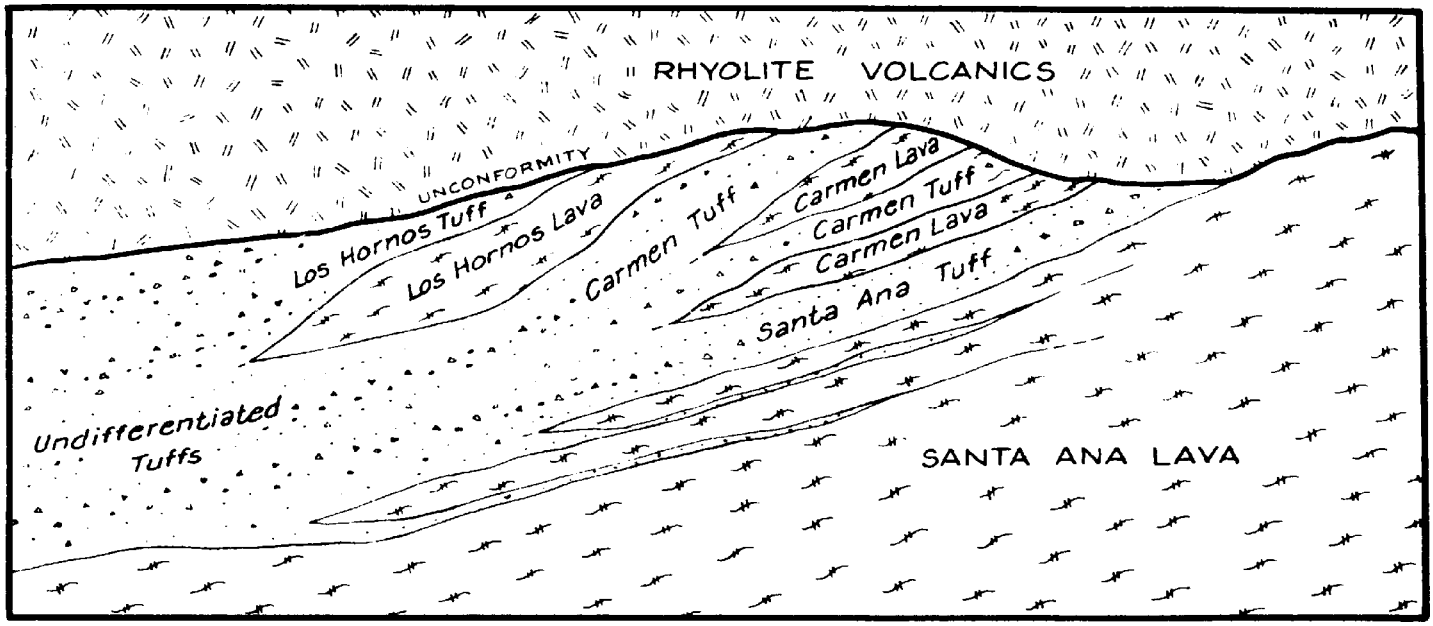


FIG. 4 **Composite diagram of the Topia Andesite, Topia, Durango, Mexico.**

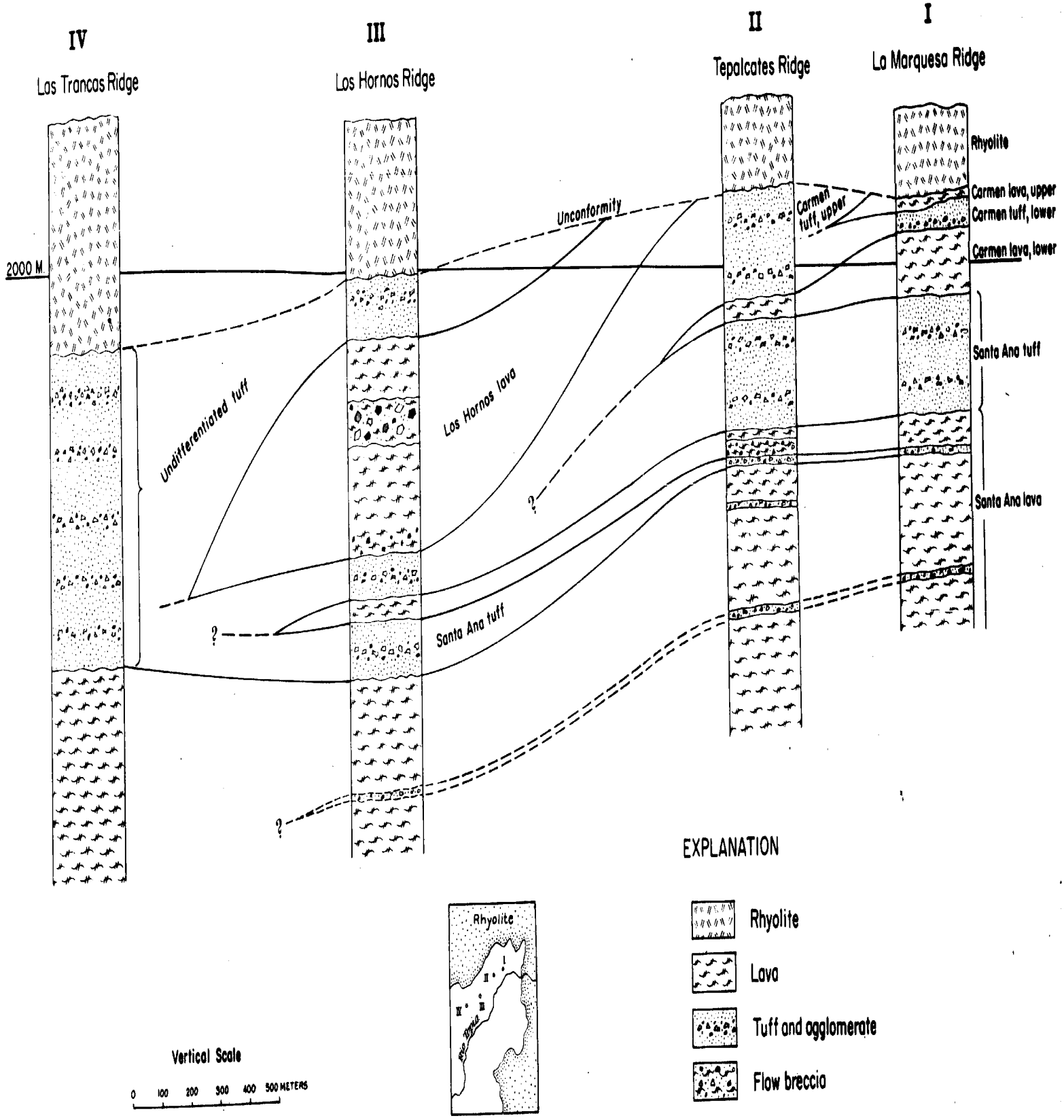


FIG. 5 The sequence of the Topia Andesite, Topia, Durango, Mexico.

Figure 6--Bedding features in the pyroclastic material of the Santa Ana tuff unit in the vicinity of the Tres Varones mine. Note crossbedding to the right of the pick head.

Figure 7--Pebble dike (left) and diabase dike (right) cutting andesite tuffs west of the Tres Varones mine. Pick handle lies along the contact between the dikes.

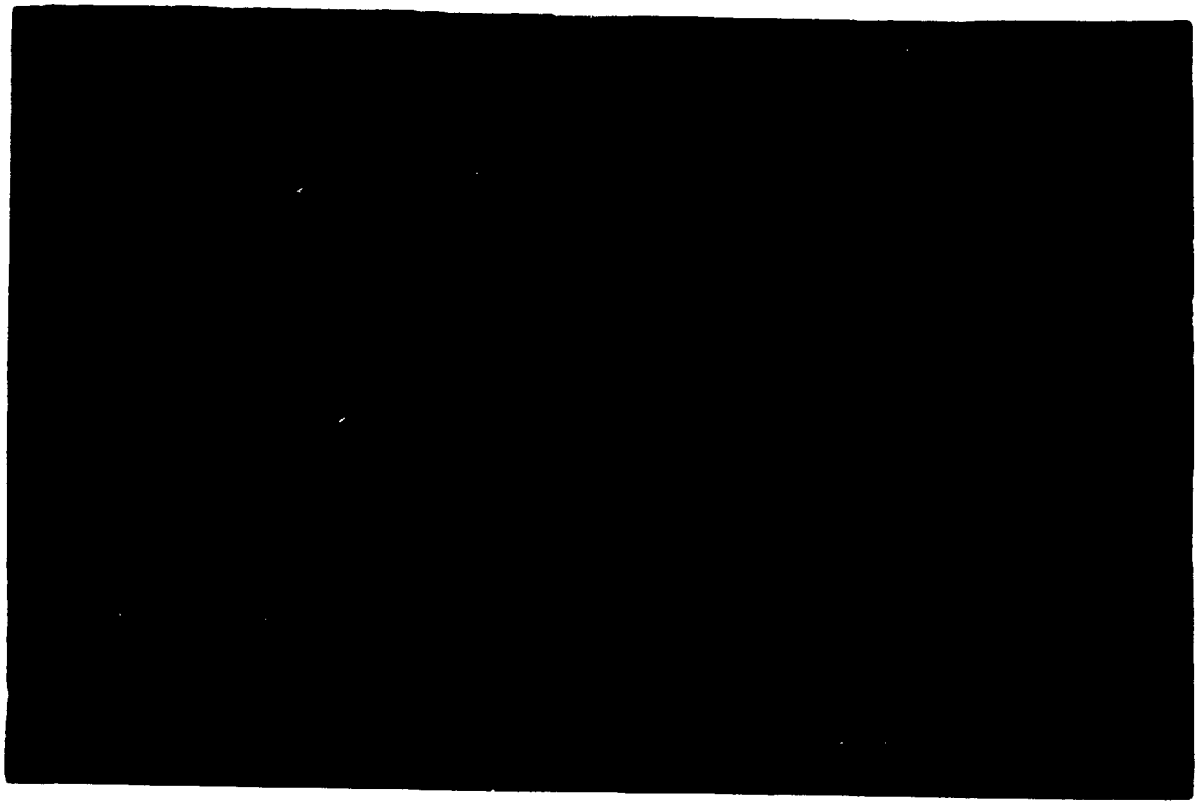


Fig. 6



Fig. 7

section of andesite in which the effects of an irregular topography were eliminated in the lower part of the section.

Santa Ana Member

The Santa Ana is the largest and most widespread division. It is composed of a series of tuffs and lavas which form the base of the Topia andesite throughout the district. Because erosion has not yet penetrated the base of this member, its true thickness is not known, although over 545 meters (1800 feet) of andesitic rock is present. The member is named after the Cordon Santa Ana which is a long ridge in the central part of the district where typical rocks are well exposed. In Figure 5, column II shows a detailed section of the Santa Ana as measured along Tepalcates ridge to the bottom of the canyon.

The member is divided into three tuff units and one lava unit. The uppermost tuff unit overlies the lava throughout the district and the other two show an intertongueing relationship with the lava. The stratigraphy of the tuffs and lava is demonstrated in Figure 4 and Plate II. Both of the lower tuff units begin as thin beds occurring on the contact between two lava flows. The beds gradually increase in thickness to the southwest as the lavas feather out.

Carmen Member

The Carmen member overlies the Santa Ana in the

northern part of the district. It is poorly exposed and consists of four units with a total thickness of about 400 meters (1300 feet) in the northeastern corner of the andesite window. The member gradually thins to the west until it disappears in the vicinity of Topia. It is named after a large mining claim called "El Carmen" on which it is most extensively exposed along the northern part of La Marquesa ridge. The detailed stratigraphy typical of the member along the ridge is shown in Column I of Figure 5.

The Carmen is divided into four units: a basal lava, an overlying tuff, an intermediate lava, and an uppermost tuff. Both lava units are essentially elongate lenses which thin rapidly and terminate to the southwest. The two tuff units merge where the intermediate lava pinches out. The combined tuffs then merge with the uppermost Santa Ana tuff in the vicinity of Topia where the basal lava unit ends. The stratigraphic details of the Carmen member are best demonstrated in Figure 4 and on the structure sections A-A' and B-B' of Plate II.

Los Hornos Member

The Los Hornos is the uppermost member of the Topia andesite. It overlies the Carmen member north of Topia, but elsewhere in the district it lies directly on the Santa Ana. The Los Hornos has a thickness of about 450 meters (1500 feet) immediately east of Topia, and it gradually thins to the southwest. The member is named after Los Hornos ridge which is a very prominent ridge flanking the

west side of Topia where the section is typically exposed. Column III of Figure 5 gives the detailed stratigraphy along the southeast spur of Los Hornos ridge.

The Los Hornos consists of two units; the lower lava and the upper tuff. The lower lava is a thick lense of lava and flow breccia which thins out rapidly to the west. The tuff unit outcrops only on the north side of Rio Topia. In the southern part of the district only the erosional remnants of the lava unit can be seen overlying the Santa Ana member. The stratigraphic relationship of the Los Hornos member to the others is shown in Figure 4 and in the structure sections of Plate II.

Undifferentiated Tuff

Along the western margin of the area, all the tuff units of the Santa Ana, Carmen, and Los Hornos members merge to form a great thickness of tuffs that cannot be differentiated. A typical section of this tuff as measured on the main spur of Las Trancas ridge is shown in column IV of Figure 5. Over 545 meters (1800 feet) of tuffs is exposed on the ridge. In the extreme western part of the district, this tuff rests directly on the Santa Ana lava unit, the other lava units in the Topia andesite having disappeared. Nearly all this undifferentiated tuff has been propylitically altered.

Petrography

The Topia andesite is composed of rocks of pyroclastic and flow origin which are all augite andesites. Where unaltered, the rocks are shades of purplish-gray on fresh fracture. The weathered surfaces generally have a brownish cast.

The rocks of flow origin are usually porphyritic, containing poorly aligned phenocrysts of plagioclase and augite in a fine-grained groundmass. The rectangular plagioclase phenocrysts range from 2 to 5 millimeters in length and the augite phenocrysts average about 2 millimeters. The only non-porphyritic lava occurs south of Rio Topia as part of the Los Hornos member.

The chief minerals seen under the microscope include andesine (Ab_{65} to Ab_{55}), augite, magnetite, apatite, and zircon. In many of the specimens the larger phenocrysts of plagioclase are broken (Fig. 9). Albite twinning is very common, and zoning is present in some of the phenocrysts. The groundmass texture ranges from microgranular to the typical pilotaxitic texture of andesites, in which microlites of andesine show a parallel alignment. The microlites have a slightly higher albite content than the phenocrysts. The groundmass is free of glass and is holocrystalline. In some specimens small crystals of pigeonite are dispersed among the microlites. Apatite and magnetite are the common accessories but some sphene and zircon are

present. No hornblende or biotite was seen in any of the rocks.

The pyroclastic rocks show a great deal of variation in the size and degree of sorting of the component fragments. The grain size ranges from some so fine-grained that the rock resembles a compacted felsite, to others so coarse that they are boulder agglomerates. The most common variety is a tuff with silt-size purplish groundmass which surrounds larger odd-sized chloritized fragments. This gives the rock a mottled purple and green appearance.

Under the microscope the pyroclastics are seen to be made up of the typical augite andesite fragments having the same minerals and textures as described for the lavas. The fragments are generally imbedded in a mixture of finer groundmass material consisting of crystal fragments and probable ash (Fig. 8, A-B). The specimens of andesite tuff and agglomerate contain a few scattered grains of quartz which are angular or corroded in shape. The quartz grains are syngenetic and an integral part of the rock; they are believed to be of detrital origin.

Deuteric Alteration

Although the Topia andesite is fresh in appearance throughout the central part of the district, many specimens show a very mild degree of alteration which is considered to have occurred at the time of the consolidation of the lavas. Small amounts of secondary minerals such as chlorite,

calcite, albite and rare quartz are present in many of the apparently fresh andesites (Fig. 9). The augite phenocrysts are partially or wholly altered to a pale green low-birefringent chlorite containing minor amounts of calcite and isolated crystals of quartz. The plagioclase is also replaced by albite. The groundmass is very fresh and only the phenocrysts show any alteration. The mild degree of alteration cannot be correlated with any possible controls such as veins, faults, and surfaces of flows. Burbank (1932, p. 80) in his study of the andesites of the Bonanza district, Colorado, concluded that the constant association of chlorite, calcite, and quartz represented a weak alteration related to the consolidation of the lava. Coats (1941, p. 11), who studied the type area of propylitic alteration at the Comstock Lode, Nevada, noted a similar alteration of the mafics in relatively fresh andesites with no apparent control. He attributed this low-grade widespread alteration to deuteric activity at the time of lava consolidation. Further indication of alteration at the time of volcanic activity is the presence of chloritized fragments (Fig. 8, A-B) in the fresh purplish-gray groundmass of the tuffs which are widely distributed throughout the district.

Age and Correlation

The Topia andesite can without doubt be correlated with the andesite lying unconformably beneath the rhyolites

throughout the central Sierra Madre Occidental. Individual units and local members cannot be traced beyond the district but the formation as a whole is very likely the equivalent of the late Cretaceous andesites and the lower part of the early Tertiary volcanics described by King (1939, pp. 1677-81).

The Topia andesite represents the oldest rock now exposed in the district. Since the bottom of the andesites at Topia cannot be seen, the actual stratigraphic position is in doubt and therefore, even though Fries (personal communication) believes them to be most likely of early Tertiary age, a late Cretaceous(?)-early Tertiary age is assigned to them. This age assignment may have to be revised when more is known of the region.

QUARTZ MONZONITE

A single exposure of a gray-green quartz monzonite occurs in the bottom of the tributary canyon of Rio Topia about 600 meters south of the portal of the Tres Varones mine at coordinates 3850 N., 4200 E. (Plate I). The area of outcrop measures 50 by 100 meters.

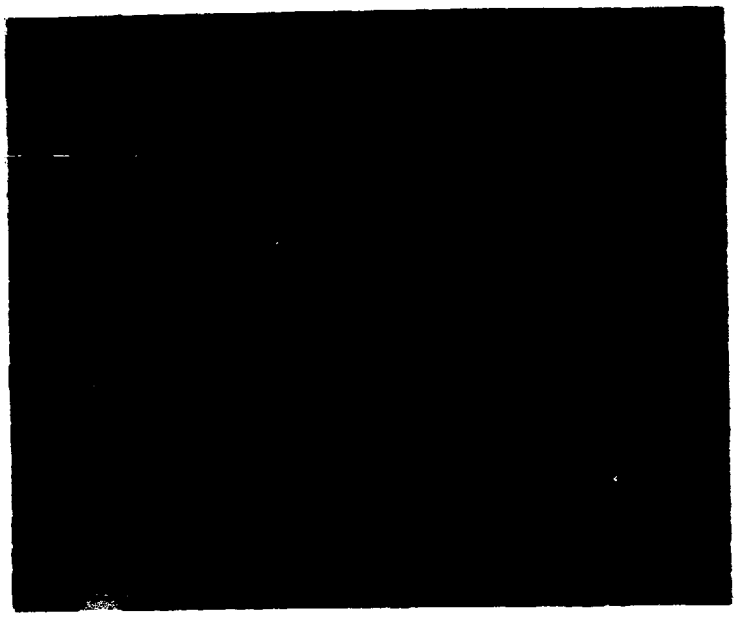
The greenish-gray rock has a medium to fine-grained equigranular texture with a few phenocrysts of feldspar that range from 2 to 5 millimeters in length and do not cause a conspicuous porphyritic appearance. The minerals seen under the microscope are andesine (Ab_{60}), orthoclase, quartz, biotite, and hornblende with minor amounts of accessory

Figure 8A--Andesite tuff from diamond drill hole 350 meters east of Topia. Some of the fragments are partially altered to calcite and chlorite. Plane polarized light. X 65.

Figure 8B--Same as above. Dark area in lower left corner is a chloritized fragment. Crossed nicols. X 65.

Figure 9 --Andesite lava from the mine dump at the Socavon Victoria. The phenocrysts of andesine are partially albitized and broken The square augite pseudomorph has been altered to chlorite and calcite. Crossed nicols. X 65.

Figure 10--Quartz monzonite porphyry from Tres Varones creek. Phenocrysts of andesine occur in a groundmass of fine-grained quartz and orthoclase. Crossed nichols. X 55.



8-A



8-B



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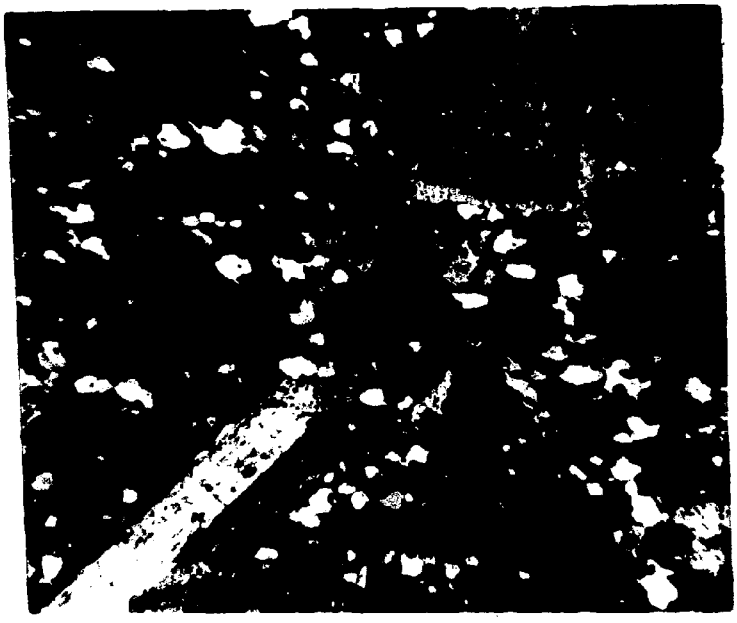

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apatite. The andesine occurs as larger phenocrysts imbedded in a quartz-orthoclase groundmass (Fig. 10). The secondary alteration minerals are not abundant and are typical of the propylitic suite which included calcite, albite, allophane, chlorite, epidote, and some sericite and hydromica.

The intrusive is bordered on the south by a N.70°E. fault but elsewhere the contact appears to be parallel with the bedding of the Santa Ana tuff. The rock adjacent to the intrusive is a white, dense, altered agglomerate which consists of sericite, calcite, pyrite, and patches of tourmaline (schorlite variety) in the form of radiating, dark, blue-green rosettes. The tourmaline is the product of contact metasomatism during the intrusion of the quartz monzonite. The quartz monzonite is later than the andesite and earlier than the mineralization. This is based on the contact metamorphism of the andesites and the presence of a small vein as well as one of the post-mineral diabase dikes which cut the intrusive.

The mineralogical composition of the rock, as determined by a Rosiwall analysis, was found to be: quartz, 24.5%; orthoclase, 26%; plagioclase, 34%; biotite, 12.5%; hornblende, 3%. It is considered a quartz monzonite on the basis of Johannsen's classification (1939, p. 144).

GRANODIORITE STOCK

Distribution

The granodiorite forms a large intrusive body exposed in the canyon of Rio Pinos and Rio Topia 5 kilometers southwest of Topia at an elevation of 800 meters. The outcrop of the intrusive has a rough rectangular shape about 2 kilometers long and 1 kilometer wide (Plate III). The trend of the intrusive is northwest which is the same as the prominent border fault that forms the eastern contact. The emplacement appears to have been controlled by the fault. The relations of the intrusive to the andesites and to the rhyolite-andesite unconformity indicate that the intrusion of the granodiorite took place at a relatively shallow depth.

Petrography

The granodiorite is a light, grayish-white rock with a black speckled but not a conspicuously prophyritic appearance because of the phenocrysts of biotite which average 2 to 4 millimeters in diameter. On weathering the rock breaks down into a light, buff-colored, coarse soil.

The rock shows a moderately coarse-grained texture under the microscope. The chief components are euhedral plagioclase (andesine, Ab_{66}) and subhedral quartz and orthoclase (Fig. 11). Brown biotite and a green hornblende are the mafics present, and the accessory minerals include apatite, zircon, and magnetite. The rock on the whole is

fresh, but some secondary minerals are commonly found in the propylitized rocks. Green pennine-type chlorite replaces many of the biotite and hornblende phenocrysts and a few grains of epidote occur in the altered mafics. Dusty-brown minute grains of allophane are common throughout and small flakes of hydromica and sericite are found in the plagioclase. A few small patches of albite are seen in some of the plagioclase.

On the basis of Rosiwall analyses, the rock has the following mineral composition: quartz, 35%; orthoclase, 13%; plagioclase, 49%; biotite, 6.5%,; and hornblende, 2%. Thus it is a granodiorite according to Johannsen's classification (1939, p. 144). Texturally and mineralogically the quartz monzonite appears to be a fine-grained equivalent of the granodiorite when the two intrusive rocks are compared under the microscope. The difference in composition can be accounted for by the fact that the phenocrysts of andesine are less common in the quartz monzonite than in the granodiorite; this would increase the percentage of quartz and orthoclase in the Rosiwall analysis. The quartz monzonite plug is believed to be related to the granodiorite stock at depth and probably represents a border facies of the main intrusive.

Contact Metamorphism

An aureole of thermally metamorphosed andesite surrounds the granodiorite (Plate III). The metamorphosed

andesite retains its dark purplish color but it has been altered to a dense low-grade hornfels. Considerable banding and streaking are present because of the introduction of silica and mica during the metamorphism. A study of the thin sections shows the andesite has been converted into a muscovite-biotite-quartz rock. Small, stubby, dark-brown crystals of tourmaline which average .15 millimeters in length are common throughout the rock (Fig. 12). In some specimens the relict porphyritic texture of the andesite is still retained and can be recognized by the rectangular outline of the ghosts of former plagioclase phenocrysts selectively replaced by quartz. A very minor amount of pyrite, magnetite, and apatite is present in the rock.

Age and Correlation

The granodiorite has intruded and metamorphosed the andesite and is therefore definitely of post-andesite age. The strong metamorphism of the rocks east of the border fault indicates that intrusion occurred after the initial phase of northwest faulting. Although the granodiorite lacks a common contact with the rhyolite, the intrusion is considered pre-rhyolite in age. In view of the close relationship between the propylitization and the intrusion and the pre-mineral age of propylitization, it is concluded that the granodiorite is also pre-mineral. Intrusion, alteration,

and mineralization are considered to be genetically related.

Not enough is known about the general geology and distribution of the intrusives in the Sierra Madre Occidental to correlate the granodiorite. Several intrusives cutting the andesites were reported in the barranca section by Santillan (1929, p. 15) but no age was given. King (1939, p. 1693) also reports several intrusives in the northern Sierra Madre Occidental and cites the age as sometime between late Cretaceous and late Tertiary. The granodiorite is tentatively assigned an early Tertiary age, perhaps Oligocene or older.

QUARTZ LATITE DIKE

A single dike of intermediate composition outcrops on Los Hornos ridge about one kilometer west of Topia. The dike has a northwest strike and dips to the east 70° to 80°. It extends continuously for about one kilometer from the rhyolite contact south along the crest of the ridge, and thence intermittently down to the bottom of the canyon where it is last seen at a place called Molinos. The general northwest trend of the dike suggests that its emplacement was controlled by the northwest fault system.

The rock is a medium, purplish-brown to light gray, dense, fine-grained type with a few phenocrysts of feldspar and biotite. Under the microscope the rock can be recognized as a porphyry with a trachytic groundmass of oligoclase laths in parallel alignment (Fig. 13).

Phenocrysts of quartz, oligoclase, and sanidine are scattered sparsely throughout the rock. Biotite is the only mafic constituent. Apatite and zircon are the accessory minerals. The rock is intermediate in composition and is considered to be a quartz latite. The rhyolite dikes are definitely more acid in composition because of the greater abundance of potash feldspar and quartz.

The quartz latite dike is post-andesite and pre-mineral in age. At the top of Los Hornos ridge immediately west of Topia, the La Perla vein cuts and displaces the dike. The dike is one of the earliest intrusive rocks in the district along with the granodiorite and quartz monzonite.

RHYOLITE DIKES

Several rhyolite dikes occur in the western part of the district, where, due to differential erosion, they are clearly visible on the north side of the main canyon as a series of parallel bands dipping to the northeast. The dikes vary in width from 2 to 5 meters and have a strike of N.40°W. and a general dip of 60° to 80°E. The emplacement of the dikes was controlled by the northwest fault system. The largest of the rhyolite dikes was intruded along the northern part of the strong northwest-trending Ojeda fault. The dike is exposed along the fault for a distance of over 3 kilometers from a point near the rhyolite contact south

Figure 11--Granodiorite from Rio Topia Canyon 6 kilometers southwest of Topia. The dark phenocryst of andesine (left) is surrounded by a medium-grained groundmass of quartz, orthoclase and biotite. Crossed nicols. X35.

Figure 12--Contact metamorphosed andesite lava from Rio Topia Canyon 5 kilometers southwest of Topia. A group of tourmaline crystals(top center) occur in a groundmass consisting of biotite, quartz, and muscovite. A large area of muscovite is seen along the bottom edge. Crossed nicols. X65.

Figure 13--Quartz latite from dike in Rio Topia Canyon at Molinos. The large oligoclase phenocryst is surrounded by a trachytic groundmass texture consisting of microlites of oligoclase and irregular crystals of quartz. Crossed nicols. X55.

Figure 14--Rhyolite from dike in Rio Topia Canyon 2 kilometers southwest of Topia. A trachytic texture is caused by alignment of the abundant sanidine crystals. Some irregular crystals of interstitial quartz are present. Crossed nicols. X55.



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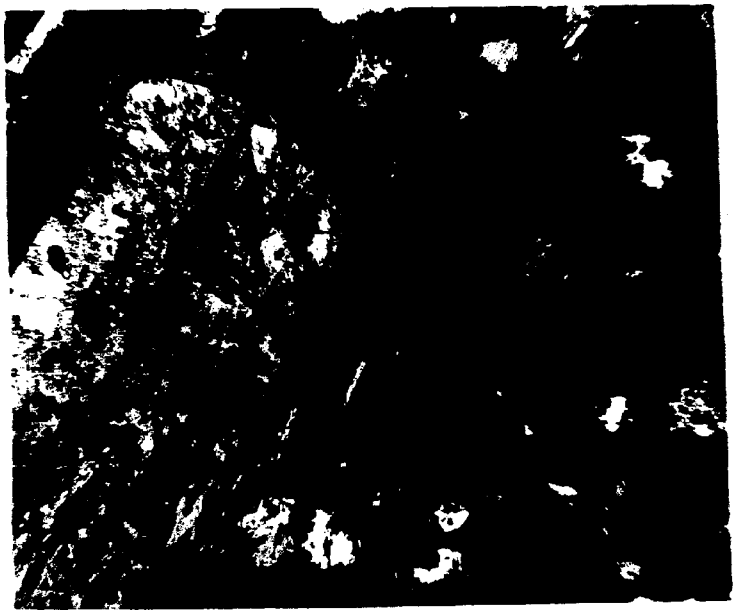

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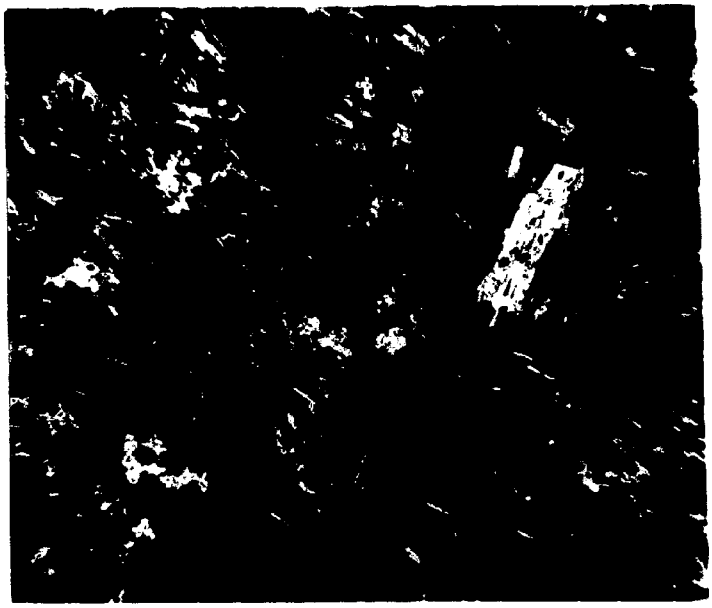

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across the main canyon almost to the top of Mt. La Ojeda.

Petrography

The rhyolite dikes are distinctive because of their light tan to buff color which is in sharp contrast to the purple-gray andesites. The typical dike has a dense fine-grained texture. and if it were not for the few phenocrysts of feldspar or biotite, it would resemble a typical fine-grained quartzite.

Thin section study of the rock shows it to be rich in potash because of the great abundance of sanidine (Fig. 14). The most striking feature is the variation in texture of the quartz-sanidine groundmass which includes a mosaic-like texture, a trachytic texture, and a feathery intergrowth texture. A few phenocrysts of oligoclase, corroded quartz, and biotite are present with magnetite as the only accessory mineral. The secondary minerals include some allophane and shreds of sericite scattered throughout the rock. Some specimens have a distinctly banded appearance due to silicification near the margins of the dike. Thin sections of the banded rhyolites show abundant allophane-spotted quartz in the groundmass also cut by clear quartz veinlets. The partially silicified dikes are generally lighter in color and have a denser appearance than the unaltered ones.

Age

The rhyolite dikes are post-mineral but probably older than the rhyolite volcanics. In the western part of the district, the Las Animas vein west of the San Felipe mine is cut off by a rhyolite dike. No common contact of the dikes and rhyolite volcanics was observed in the district although one dike comes within 100 meters of the rhyolite-andesite contact. No dikes were seen cutting the massive cliffs of rhyolite; it is therefore believed the dikes are earlier than the rhyolite flows.

DIABASE DIKES AND PEBBLE DIKES

Distribution

The diabase dikes are widely distributed throughout the central part of the district on both sides of Rio Topia (Plate III). In contrast to the rhyolite dikes and quartz latite dike, the diabase dikes have both northwest and northeast trends, and in many places are very irregular. The dikes are sill-like along some of the andesite tuff-lava contacts. Northwest faults, northeast fissures, joints, and contacts have controlled the emplacement of the diabase.

A few pebble dikes occur very close or adjacent to the diabase dikes. They generally have the same irregular trends (Fig. 7). The best pebble dike exposure seen is on the Caneles trail about 200 meters south of Topia. The pebble dikes consist of rounded to subangular pebbles and

cobbles of shale, siltstone, orthoquartzite, rhyolite, and andesite in a fine-grained limonite-stained groundmass of the same pulverized rock material. Close inspection indicates that the rounding of the pebbles is actually a multiple faceting probably caused by the attrition of pebble on pebble. The pebble dikes are of interest because they bring up rock types which underlie the Topia andesite at great depth. They are believed to be caused by the forceful intrusion of deep-seated material into the overlying andesites. The material was pushed into place by riding on top of the diabase or was emplaced as an explosion breccia. Pebble dikes very similar in appearance and origin are described by Lovering (1949, pp. 11-13) in the East Tintic district, Utah.

In the largest of the diabase dikes, which is well exposed immediately west of the Tres Varones mine, xenoliths of shale, siltstone, quartzite, rhyolite, and andesite are abundant adjacent to the contact. The only sedimentary rocks in the entire district are found either in the pebble dikes or as xenoliths in the diabase. The xenoliths are believed to be present as the result of viscous drag by the diabase at the time of intrusion.

Petrography

The diabase dikes are easily recognized because of the dark greenish-gray to black color. They are dense fine-grained rocks which lack any visible true prophyritic texture.

A pseudo-porphyritic texture is commonly caused by flattened calcite-filled vesicles.

Under the microscope the diabase has a strong trachytoid texture caused by the microlites of labradorite (Ab_{45}) in sub-parallel arrangement (Fig. 16). Few phenocrysts of plagioclase or mafic minerals are present, but numerous tiny crystals of pigeonite occur interstitial to the labradorite laths. Small irregular crystals of magnetite are seen throughout the rock, and some accessory apatite is present.

A microscope examination of the pebble dikes substantiates the megascopic observations. The entire rock is composed of sedimentary and extrusive rock fragments of sizes ranging from a fraction of a millimeter to cobbles (Fig. 15, A-B). Most of the fragments are sub-angular to rounded in shape and a crude parallel alignment exists in some specimens. Thin sections of several individual pebbles were studies, and their sedimentary origin was verified.

Age

The diabase dikes and associated pebble dikes are post-mineral and pre-rhyolite in age. Numerous examples of veins cut by both types are present on the surface and in the mines. At Las Trancas ridge west of the Tres Varones mine, a dike comes into direct contact with the overlying rhyolite but does not cut it. The exact relationship to the rhyolite dikes is difficult to ascertain because no cross

cutting structures were observed. At Molinos the diabase occurs immediately adjacent to the quartz-latite dike and farther down the canyon it is next to a rhyolite dike. Because the irregular trends of the diabase are probably caused by faults later in age than the northwest faults along which the rhyolites were emplaced, it is believed that the diabase represents the latest intrusive activity in the district and post-dates all other dikes.

RHYOLITE VOLCANICS

Distribution

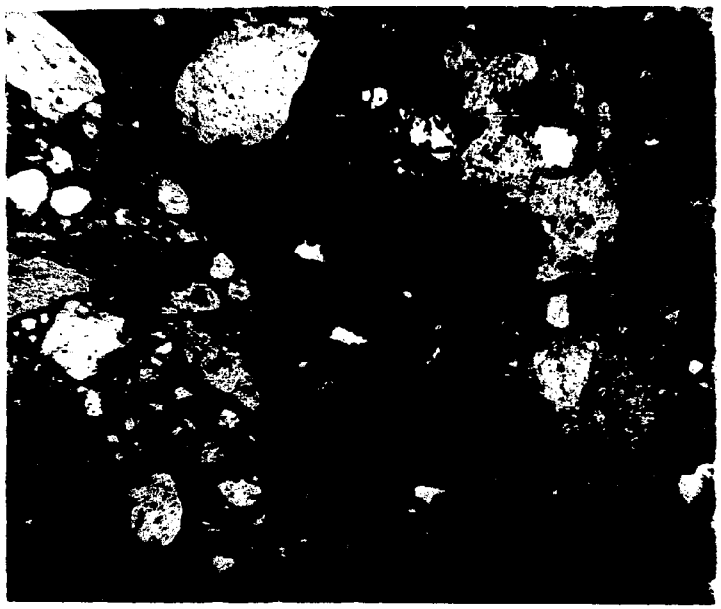
The Rhyolite volcanics form a thick sequence of acid extrusives that lie unconformably on the andesites at Topia and throughout the central Sierra Madre Occidental. The rhyolites are over 600 meters (2000 feet) thick at Topia, but the true thickness is not known because subsequent erosion has cut a rolling plateau-like surface which extends throughout the plateau section of the range. The rhyolites form cliffs wherever streams have incised them deeply. At Topia huge cliffs of rhyolite encircle the main part of the district on three sides. The various beds of rhyolite generally are conformable, and they are nearly horizontal except in the area south of Rio Topia where they have been tilted to the southwest by late faulting.

Figure 15A--Pebble dike material from pebble dike on Caneles trail 200 meters south of Topia. A large rounded fragment of siltstone (left) and smaller fragment of shale (top left) occur in a finer-grained clastic groundmass of quartz and other rock material. Plane polarized light. X 35.

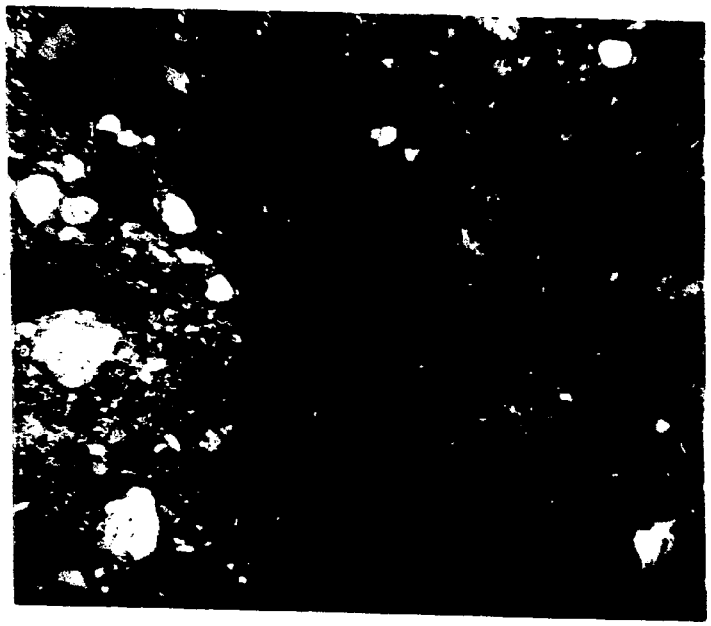
Figure 15B--Same as above. Crossed nicols. X 35.

Figure 16-- Diabase from dike 1 1/4 kilometers west of Topia. Microlites of labradorite show a subparallel alignment. Pigeonite and magnetite occur interstitially. Crossed nicols. X 55.

Figure 17-- Rhyolite tuff from a cliff 1 1/2 kilometers north of Topia. Chalcedony occurs as a lining along the walls of a cavity. Crossed nicols. X 94.



15-A



15-B



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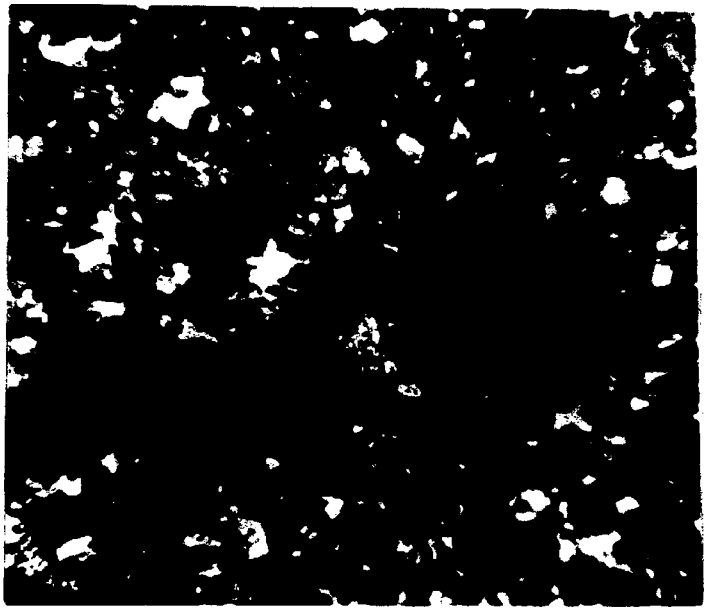

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Lithology

The Rhyolite volcanics are composed of many rock types, such as lithic and crystal tuffs, ignimbrites (welded tuffs), and true rhyolite flows. all of which are interbedded with one another. The rocks on the whole are light-colored. The composite color of the cliffs is a creamy-buff although individual units may be snow-white, pink, gray, lavender, or brown. Rhyolite flows are common in the northwestern corner of the district whereas tuffs and ignimbrites are conspicuous in the eastern part and are most abundant in the district as a whole. In a reconnaissance across the Sierra Madre from Tepehuanes to Topia, tuffs and ignimbrites were found to be by far the most common rock types exposed. and rhyolite flows were rarely seen.

The rhyolitic flows are easily recognized in the field because of the prominent flow lines which are generally highly distorted into small flow-folds and crenulations. The lavas are light pinkish-gray and have a dense groundmass containing phenocrysts of clear quartz. Thin sections of the rhyolites show the groundmass of some specimens to be very rich in glass, whereas others show a microcrystalline feathery mosaic of sanidine and quartz. Sanidine, quartz (mostly corroded), and oligoclase occur as phenocrysts and the mafic material present is biotite or hornblende. In many lavas, bands of spherulites are found between the flow layers, the spherulites consisting of radiating crystals of sanidine. A common rock of flow origin is a banded rhyolite

composed of layers of frothy pumice averaging about 10 to 12 millimeters in thickness alternating with layers of flow-laminated lava and spherulites averaging 10 to 50 millimeters across. Under the microscope, the distinctive feature of the pumice layers is the great abundance of shards of glass. These frothy pumice layers are believed to have served as glide planes along which the very viscous lava was able to flow for great distances.

The welded tuffs, a distinctive rock type, are common in the rhyolitic series at Topia. They form units of gray, buff, or pink color up to 100 meters thick. The welded tuffs, or "ignimbrites", are a pyroclastic product of the nueé ardente type of eruption that is frequently mistaken for rhyolitic lava because of its characteristic dense and well indurated texture. C. M. Gilbert (1938, p. 1830), who describes the occurrence and origin of welded tuffs in California, states that the term "ignimbrite" was used by Marshall (1935) to define the welded tuffs which make up a large part of the rhyolite plateau in New Zealand. Mackin (1950, p. 1528) also reports their occurrence in Utah. The characteristic features of the welded tuffs are the lack of flow lines and true bedding planes, the presence of fragments of pumice and other rocks, and the gradational and textural changes upward from a vitric matrix as glassy as a pitchstone to a more porous and softer matrix at the top. These features are all present in the welded tuffs at Topia. No true bedding planes such as those seen in the lithic tuffs are present, although some crude alignment of fragments

is seen. The extremely well indurated matrix of the rock contains fragments of other rhyolites as well as phenocrysts of quartz, sanidine, plagioclase and biotite. Thin sections of the rock show the presence and the random scattering of the above minerals as phenocrysts in a glass-rich groundmass without flow lines.

Crystal and lithic tuffs are also common at Topia. Several exposures of a pure snow-white crystal tuff were observed. Examination under the microscope showed the tuff to contain glass shards, phenocrysts of quartz, sanidine, and biotite, and also a considerable amount of chalcedony enclosed in small worm-like tubes (Fig. 17). The lithic tuffs are reworked pyroclastic material in which bedding planes are distinct; locally crossbedding is present. The tuffs as a whole are rhyolitic in composition.

Age and Correlation

The Rhyolite volcanics at Topia are definitely post-mineral in age. The Argentina vein can be seen underlying the rhyolites on a ridge north of Topia (Plates I and III).

The rhyolites, which are the youngest rocks of the area, can be correlated with the acid extrusives throughout the range. Fries (personal communication) believes they also can be correlated with the rhyolites of central and southern Mexico. A tentative Miocene age is assigned to the Rhyolite volcanics and the basis for the dating is discussed in the section on regional geology (General Geology).

TERTIARY-QUATERNARY GRAVELS

Abundant gravel, both consolidated and unconsolidated, covers wide areas of the Topia district (Plate I). Most of the gravels are composed of rhyolitic material carried down from the surrounding cliffs, and because of the preponderance of this material the color is generally light tan to buff. An enormous variation in size can be seen, ranging from a few blocks as large as an average house down to silt-size grains. The gravels for the most part are poorly sorted, with blocky and subangular material more common than well rounded fragments. Reddish-brown andesite gravels are present in a few places where the rhyolite source rock is distant. The gravels are the result of talus accumulation and stream deposition. The subangularity indicates that the deposits did not form very far from the source. The few enormous blocks, such as the one which occurs 200 meters northwest of Topia, are the result of landslides.

The range in lithifaction from loose material to well compacted beds, as well as the presence of terraces cut on the gravels, indicates that gravels of several ages are present at Topia. At the townsite, a well developed erosion surface has been cut on some consolidated buff-colored gravels, which are considered the oldest in the area. Several other patches of well consolidated material are found on the other erosion surfaces occurring at different levels within the canyon. The most common type however, is the loose talus sweeping down from the cliffs

and covering all of the older gravels and rocks of the area.

The age of the gravels ranges from post-rhyolite time to the present. In view of the probable Miocene age of the rhyolites, it is believed that the well consolidated local terrace gravels may be as old as the Pliocene and related to the orogenic uplift of the area when the erosion cycle of canyon cutting began.

STRUCTURE

General Statement

The overall structural picture of the district is a series of tilted andesite beds dipping to the southwest 20° to 30° as a result of faulting which has broken the rocks into step-like blocks. The unconformity separating the Topia andesite from the Rhyolite volcanics is a structural feature of regional importance. There is no folding. The dominant features, however, are the faults of different ages which form a definite pattern. The faults may be divided into three sets: (1) the major northwest set of both pre-mineral and post-mineral faults, (2) the N.60°E. set of vein fissures and post-mineral faults, and (3) the minor set of N.20°E. post-mineral faults. The northwest faults and N.60°E. vein fissures are most abundant and form the basic pattern. These two sets have, on the whole, controlled the mineralization, the emplacement of the dikes,

and the intrusion of granodiorite.

The faulting at Topia is believed to represent different periods of movement along the same lines of weakness. After the initial northwest and N.60°E. trends had developed previous to the mineralization, post-mineral high-angle normal faults formed in a northwest direction and a few formed in northeast directions. The faulting is related to the tectonic activity of the Sierra Madre Occidental which developed two trends in the range, a major northwest trend and a minor northeast trend. It is believed that most of the faulting occurred during the uplift of the range.

Plate III shows the relationships of all the structural elements in the district. In order to show the existence of similar trends in the unmapped rhyolites, features representing faults or joints were transferred from aerial photographs. The innumerable minor faults seen in the underground workings are not shown on the structural map.

The surface expression of the faults is very poor because of the widespread gravel and soil cover. The faults are best seen along contacts between andesitic tuff and lava units on cliffs and steeper slopes. In such places it is evident that faults are abundant and the district is highly fractured. Because of the cover, only a small percentage of the faults are visible on the surface and their exact relation to one another can be ascertained only in a general way.

Local Structure

Northwest Faults. The most prominent faults in the district strike N.32°-50°W. and have displacements up to 130 meters. They dip from 55° to 80° northeast. Two ages of northwest-trending faults were recognized; an earlier pre-mineral set and a later post-mineral set which is far more extensive.

The earlier set, restricted to the andesites, is not common. The age of these faults is established by their relationship to the veins. On two faults, the Ojeda and the Hornos, a small amount of mineralization is found where the veins cross the fault. The Hornos is displaced about 10 meters by the La Perla vein. The pre-mineral quartz latite dike which is controlled by an early northwest structure is also offset by the La Perla vein. In view of the later intrusion of a rhyolite dike along the largest of the pre-mineral faults, the Ojeda, it is believed that the other rhyolite dikes are also controlled by the early northwest structures. Because of the strong contact metamorphism east of the border fault, forming the eastern contact of the granodiorite intrusive, this fault is believed to have controlled the emplacement of the intrusive (Plate III). The apparent movement on the earlier faults indicates that the hanging wall (east block) has moved down.

In the main part of the district the two largest northwest faults of definite pre-mineral age are the Ojeda and Hornos. The Ojeda can be traced about 5.5 kilometers

within the mapped area and for an unknown distance south beyond the town of Caneles (Plate III). This fault trends about N.40°W. and dips 60°-70°N.E. The apparent vertical displacement in the vicinity of Mt. La Ojeda is about 100 meters with the east side down. The largest of the rhyolite dikes has been intruded along the northern half of this structure for 3.5 kilometers. South of Mt. La Ojeda the fault is a highly brecciated shear zone. In the canyon of Rio Escalera, where it is well exposed, the fault is cut by a minor vein and mineralization extends along it for a few meters. The diabase dikes cut the mineralized part of the fault and then swing parallel with it for a short distance.

The Hornos fault is exposed for one-half a kilometer on the east slope of Los Hornos ridge. It strikes N.50°E. and dips 70°N. The Los Hornos andesite tuff-lava contact is offset about 50 meters vertically. the east side having moved down. The La perla vein displaces the fault about 10 meters to the east on the south side and mineralization spreads along the fault for a few meters. This demonstrates the pre-mineral age of the fault.

The post-mineral northwest faults, which are the most abundant in the district, cut both the rhyolites and the andesites. Northwest trends are very common in the rhyolites, and the drainage and topography on the rhyolite erosion surface is controlled by them. In the eastern part of the district, the rhyolite-andesite contact is essentially a fault contact formed by the late northwest faulting. These late faults are commonly observed in the underground

workings where the vein is generally offset a meter or less and the east block moves south. Only in a few places are the veins displaced on the surface although the same faults offset the post-mineral rhyolites of low dip. This suggests a strong component of vertical movement. In two places where enough information is available to determine the displacement, a strong vertical component of movement was indicated. All of the later northwest faults seem to be of the normal type. From east to west the most prominent faults of post-mineral age are: the Madrid, the Carisso, the Victoria, and the Gregorio.

The Madrid fault can be traced across the central part of the district for more than 6 kilometers (Plate III). The strike averages N.32°W. and the dip varies from 50°E. in the canyon of Rio Escalera to 80°E. north of Topia. In the Rio Escalera area, the Madrid fault has displaced and tilted the Rhyolite volcanics on the east against the Topia andesite. The displacement is estimated to be over 100 meters south of Rio Topia and about 50 meters to the north. It is believed to increase farther south.

The Carisso fault can be followed for a distance of 2.5 kilometers (Plate III). It strikes about N.48°W., dips 75°E. and the displacement is approximately 50 meters with the east block down. It is very close to the Victoria fault and may be related to it.

One of the most persistent faults in the district is the Victoria which is traceable across the andesites and rhyolites for at least 10 kilometers (Plate III). It

passes under the town of Topia and is probably the main cause for the erosion which has produced the large flat embayment on the north side of the canyon. The general trend is N.42°W. and the dip averages 70°E. The fault is best exposed at the portal of the Socavon Victoria (Victoria tunnel) where the andesites have been brecciated over a wide area. South of Rio Topia, the rhyolites are displaced and tilted by the fault which also has offset the northeast Santa Ana fault in the canyon of Rio Carisso. A total net-slip of 83 meters on the Victoria fault is indicated by the offset of the Santa Ana and by displacement of the andesite tuff-lava contact. The dip-slip component is 78 meters and the strike-slip 28 meters. The hanging or east wall moved down and to the north.

The Gregorio is the easternmost major northwest fault and can be followed for 7.5 kilometers (Plate III). It is well exposed in several places where it has a N.49°W. strike and a dip of 68°E. The displacement is about 50 meters or less north of Rio Topia and over 130 meters south of the river. The fault offsets the La Perla vein about 10 meters to the south on the east side.

On some of the later northwest faults the displacement increases to the south. This is also apparent in the rhyolites which north of the town are essentially flat-lying, whereas south of the town they are tilted. Several strong northwest trends which appear to be the continuation of the larger structures are seen in the aerial photographs of the vicinity near the town of Caneles, which is

about 10 kilometers south of Topia.

N.60°E. Fissures and Faults. Two groups of faults with an average N.60°E. trend are present in the district. The first group includes fault fissures which were mineralized to form the veins. Post-mineral faults, represented by the San Miguel and Molinos faults, comprise the second group.

The mineralized fault fissures or veins range in strike from N.48°E. to N.72°E. but generally average N.60°E. They dip to the south at an average of 80°. (For detailed description, see Ore Deposits.) The veins are persistent with the longest vein in the district, the La Perla, having a length of at least 4 kilometers. The displacement along the pre-mineral fissures is not as large as along the major northwest faults but the horizontal component of movement is relatively strong. Along the La Perla vein at Tepalcates ridge the net-slip is 53 meters with a strike-slip component of 51 meters and a dip-slip component of 19 meters. The south or hanging wall moved down and to the east which indicates right-hand movement. On several other veins where contacts have been displaced, the movement is of the same nature although apparently not as great. Characteristic of the La Perla vein and several others are the numerous veinlets that branch off at low angles (Fig. 34). These veinlets appear to be tensional fractures which swing away from the veins to a more northerly trend, forming acute angles which conform with the right-hand movement. The northeast

fissures are believed to be the major shears of pre-mineral age. Although one of the pre-mineral northwest faults is offset by veins, not enough is known about the relationship of the northeast fissures and early northwest faults to determine which occurred first, or whether they are of about the same age. McKinstry (1948, p. 353) states that faults which form at about the same time and meet at a large angle are likely to be complementary even though one may offset the other. At Topia, however, this may not be the case because the displacement on some of the larger early northwest faults (Ojeda and Hornos) is greater than that on the vein fissures.

In the underground workings, there is evidence of post-mineral faulting parallel with the veins. These faults follow the veins and then peel off into the walls. Horizontal striations are commonly seen along the fault planes, and at the place where the offset could be observed right-hand movement similar to that of the pre-mineral fissures is indicated. (See Ore Deposits.) The presence of later faulting along the veins shows that post-mineral adjustment has taken place along older lines of weakness.

The San Miguel strikes N.70°E., dips 70°S., and is traceable on the surface for 1.5 kilometers. In the San Miguel mine it offsets the Cantaranas vein (Fig. 37) horizontally 50 meters to the west on the south side (hanging wall). The Molinos fault which trends N.60°E. and dips north at a high angle, is believed to control the course of Rio Topia in the central part of the district (Plate III).

Farther to the west this fault offsets a rhyolite and diabase dike 10 meters to the east on the north side. The vertical component of movement in which the north block moved down is much greater and is estimated to be from 150 to 200 meters on the basis of displacement of the Santa Ana member (structure section F-F', Plate II). The Molinos fault is of late age as it offsets post-mineral dikes.

N.20°E. Faults. A few N.20°E. faults, such as the Santa Ana and the minor ones which offset the quartz latite dike, are present in the district (Plate III). With the exception of the Santa Ana, minor displacements are indicated for most of them. The Santa Ana, which trends N.20°E. and dips S.E. at a high angle, can be traced for about 6 kilometers. Its displacement appears to be variable, the largest amount being about 50 meters with the south side down. In the underground workings, some N.20°E. faults displace the veins from one to two meters to the south on the east (hanging wall) side. The age of this set cannot be determined exactly. The presence of N.20°E. trends in the post-mineral rhyolites and the offset of the veins indicate a post-mineral age. However, the displacement of the Santa Ana fault by the Victoria in Rio Carisso canyon suggests the N.20°E. faults are somewhat earlier than the late northwest faults.

Origin of the Faulting. The pattern formed by the combination of the northwest, N.60°E., and N.20°E. faults is believed to be the result of regional tectonic activity

in the Sierra Madre Occidental. The different ages of the faults denote recurrent activity along the same directions throughout the Tertiary history of the region.

Two sets of faults, the pre-mineral northwest set with normal-type displacement and the N.60°E. fissures, represent the initial faulting which established the basic pattern. The displacement of one of the northwest faults by the veins indicates that the northwest set is probably the earliest. The fissures delineate the dominant shearing direction resulting from tectonic activity previous to the mineralization. The northeast orientation of the fissures with their northerly trending tensional breaks suggests that the shearing could be the result of a north-south compressive force or possibly a northeast-southwest regional couple. (See Fig. 34.) East-west compressive forces which probably existed in the region during the Laramide folding of the basement rocks prior to the deposition of the andesites, were most likely inactive when the intital pattern developed. Local forces resulting from doming during the intrusion of the granodiorite may have been present in pre-mineral time but are not considered to be responsible for the initial pattern. The pre-intrusive northwest border fault which appears to have controlled the emplacement of the granodiorite implies a pre-intrusive age for the northwest set. Local forces, however, may have aided the mineralization by keeping the fissures open. The presence of similar northeast-trending veins in districts near Topia indicates that forces which created the fissures were most

likely regional. (See Ore Deposits.)

Renewed tectonic activity in post-mineral time favored displacement along the northwest direction and to a lesser degree along the N.60°E. and new N.20°E. trends. The total cummulative displacement on the northwest faults far exceeds that of the others. The post-mineral movement along the veins may represent the adjustment of the blocks at this time. The exact relationship of all the post-mineral faults is not known but the results at Topia agree with the view of McKinstry (1948, p. 304), who states that later faults generally follow pre-existing lines and may also create new fractures of their own. This appears to be the case at Topia where post-mineral northwest, N.60°E., and a new set of N.20°E. faults have formed. The presence of strong northwest and subsidiary northeast trends in the rhyolites of the Sierra Madre Occidental indicates that post-mineral regional forces were operative in Topia. Orogenic uplift of the range in post-rhyolite time (King, 1939), which resulted in recurrent activity during late Tertiary and possibly Pleistocene time, is probably the main cause of the post-mineral faulting.

Unconformity between the Topia Andesite and Rhyolite Volcanics

The major erosional unconformity between the andesites and overlying rhyolites is best seen along the contact of the two formations north and west of Topia (Fig. 18). The unconformity is exposed intermittently for about 4

kilometers. Mapping has demonstrated that it represents a mature erosion surface cut on the andesites (Fig. 4). This rolling surface gradually climbs to a maximum elevation of 2175 meters near the Manzanilla vein where the northernmost andesites are exposed. The andesites here represent the topographic high of the pre-rhyolite surface for the entire district; from this point the contact between the rhyolites and andesites gradually decreases to the south and west. The rhyolites along the northwest contact are almost flat-lying and have an angular relationship with the tilted andesites (Fig. 4). In some places the rhyolites have been deposited against hills developed on the andesite surface. Some old soils have been noted along parts of the unconformity, and in one place the soil merges gradually with a light-colored partially consolidated and crossbedded lithic tuff which represents the base of the Rhyolite volcanics. The lowest elevation reached by the unconformity is in the canyon of Rio Pinos north of the granodiorite stock at an elevation of about 1400 meters. This indicates that differential erosion was intensive in the vicinity of the intrusion probably because of fracturing and widespread propylitic alteration. The present difference in elevation between the unconformity and the highest granodiorite exposure is estimated to be 200 meters. Although a considerable thickness of andesite was probably eroded after intrusion, it is believed that the granodiorite was emplaced in a shallow environment.

The same type of unconformable relationship is

present between the rhyolites and andesites throughout the central Sierra Madre Occidental. It is mentioned by King (1939) and Santillan (1929) in regions north and south of Topia. The regional nature of the unconformity is of major importance in dating and correlating the sequence of events in Topia with the rest of the range. In view of the faulting, tilting, intrusion, alteration, mineralization, and erosion prior to the deposition of the Miocene(?) rhyolites, it is believed that the unconformity represents a period of erosion that could have occurred in the Oligocene or even early Miocene. At Topia the lack of gravels along the unconformity indicates the region was a high erosional area in pre-rhyolite time.

GEOMORPHOLOGY

General Features

The dissection of the western slope of the Sierra Madre Occidental has produced a region of extreme relief typified by canyons and sharp divides known as the "barranca" section. (See Introduction.) Topia is uniquely located at the western edge of the barranca where it joins the undissected plateau, and as a result two contrasting types of topography exist in the area. The rolling accordant erosion surface on the rhyolites of the plateau section surrounds the bowl-shaped mining district. The district itself lies within a canyon which is part of the barranca

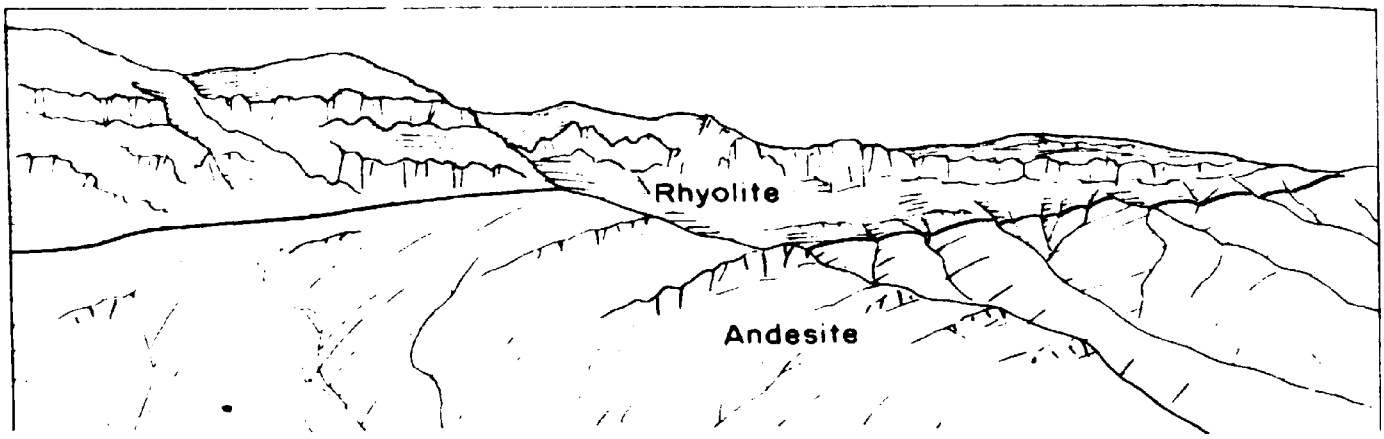


Figure 18--View of the north side of Rio Topia Canyon showing the unconformable relationship of the horizontal rhyolites and the tilted andesites.

Figure 19--Looking at the northeast side of Rio Topia Canyon where the broad sloping intermediate surface is being dissected by stream erosion to form the inner gorge.



Fig. 18

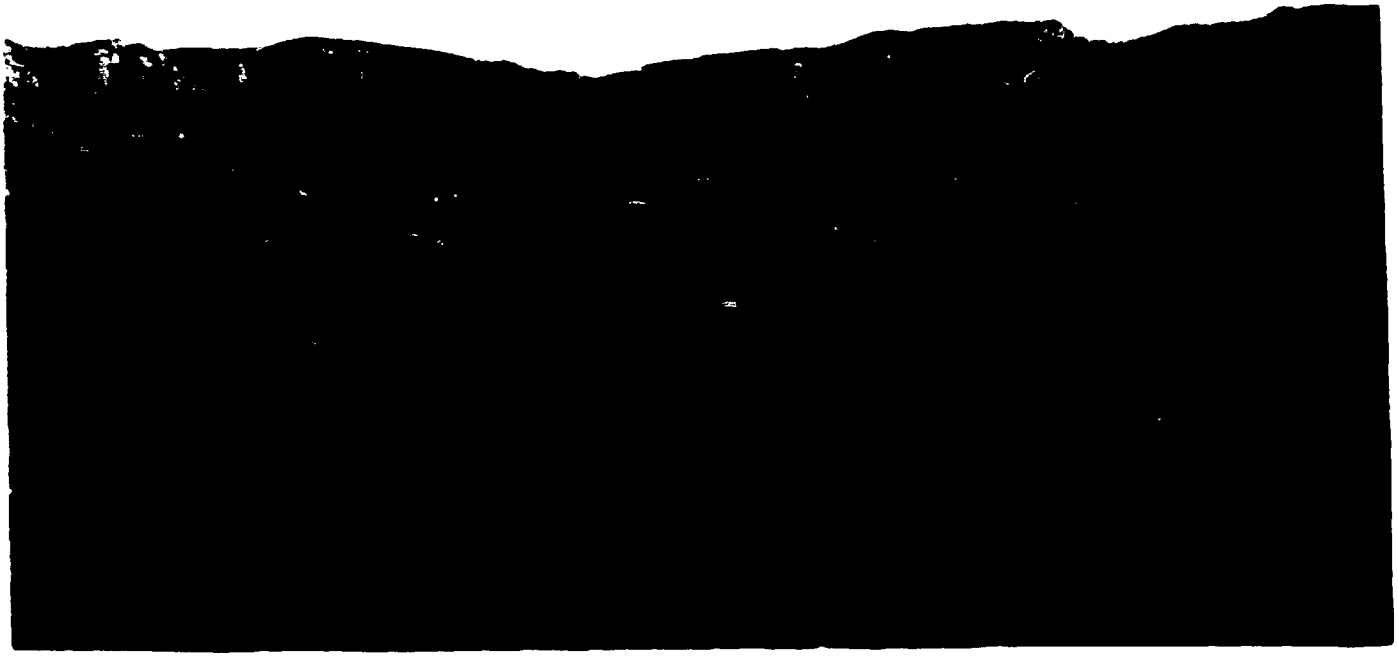


Fig. 19

section. This canyon is the major topographical feature and can be divided into two parts; the broad open upper half consisting of the high cliffs of rhyolite surrounding the wide sloping inner surfaces which were the result of earlier valley widening processes, and the deep narrow inner gorge which was formed when the Rio Topia incised the inner surfaces. At least two stages of erosion are in evidence in the upper half of the canyon and a third stage is represented by the inner gorge. The various stages which developed the canyon are believed to be related to the late Tertiary-Quaternary history of the region and possibly to Pleistocene climatic changes.

The distinctive northwest and northeast fault trends have exerted a definite structural control on the drainage pattern of the local streams in a manner similar to the rectangular pattern present in the region as a whole.

Erosion Surfaces and Canyon Development

The best developed surface in the area is the rolling accordant erosion surface developed on the relatively flat-lying rhyolites throughout the Sierra Madre Occidental. At Topia the plateau surface has an average elevation of about 2300 meters but is much higher in parts of the Sierra. It has formed since the deposition of the rhyolites in Miocene(?) time. The profile of the plateau surface can be traced across the range and down the eastern flank to the town of Tepehuanes which is 70 kilometers due east of

Topia (Fig. 3). The town lies in a gravel-filled basin of the Mesa del Norte. Here the gradually sloping plane coincides with the upper surfaces of the preserved parts of the basin gravels, which are deeply dissected and are being stripped away by the present erosion cycle. On the western slope of the range the plateau is attacked by headward erosion of streams draining into the Pacific Ocean.

Below the plateau surface and within the canyon itself, there are several topographic features directly related to the development of the canyon. In the upper half, erosion at two different stages has left surfaces which give the district a broad,open, basin-like form (Fig. 1, Frontispiece; Fig. 19). The lower half is a deep narrow inner gorge with several river terraces which together represent a third stage of erosion still in progress (Fig. 19). Three profiles across the canyon demonstrate the relationship of the surfaces in the upper part to the inner gorge and its related terraces (Fig. 20).

The uppermost surface present in the canyon has an average elevation of 1850 meters and occurs immediately below the rhyolite contact. It is not well preserved and only a few remnants remain. It is represented by profiles A-A' and B-B' of Figure 20. The surface is best seen on Los Hornos ridge immediately west of Topia where it is cut on the andesites and some consolidated rhyolite gravels. It can be correlated to a well developed surface at similar elevations near the town of Caneles which lies in a canyon 10 kilometers south of Topia.

The intermediate surface, the most prominent and best developed in the canyon, is at elevations of 1500 to 1700 meters in the central part of the district. The profiles of Figure 20 show its broad outline. The surface, consisting of a series of straths and berms cut on the andesites and consolidated rhyolitic gravels, is at present being dissected. It forms the only parcels of moderately level ground and is the site on which the town of Topia is located. The intermediate surface gradually slopes to the center of the canyon and downstream at a steeper angle (Fig. 1, Frontispiece; Fig. 19).

The remaining surface consists of some river terraces in the central part of the district at an elevation of 1300 to 1400 meters within the inner gorge. Figure 20 shows the successive decrease in elevation of terraces in a downstream direction.

Figure 21, a diagrammatic sketch showing the successive stages of erosion in the development of Topia canyon, is based on the evidence available at Topia and Caneles. Because of the Miocene(?) age of the rhyolites and the Pliocene orogenic uplift of the Sierra Madre Occidental, the great amount of erosion which created the canyon dates from the Pliocene to the present. It is believed that the upper and intermediate surfaces, which formed during the Pliocene, developed successively two broad valleys during the early history of the canyon. The presence of the surfaces on the andesites and consolidated gravels indicates an early age for both. The sharply incised "V" shaped

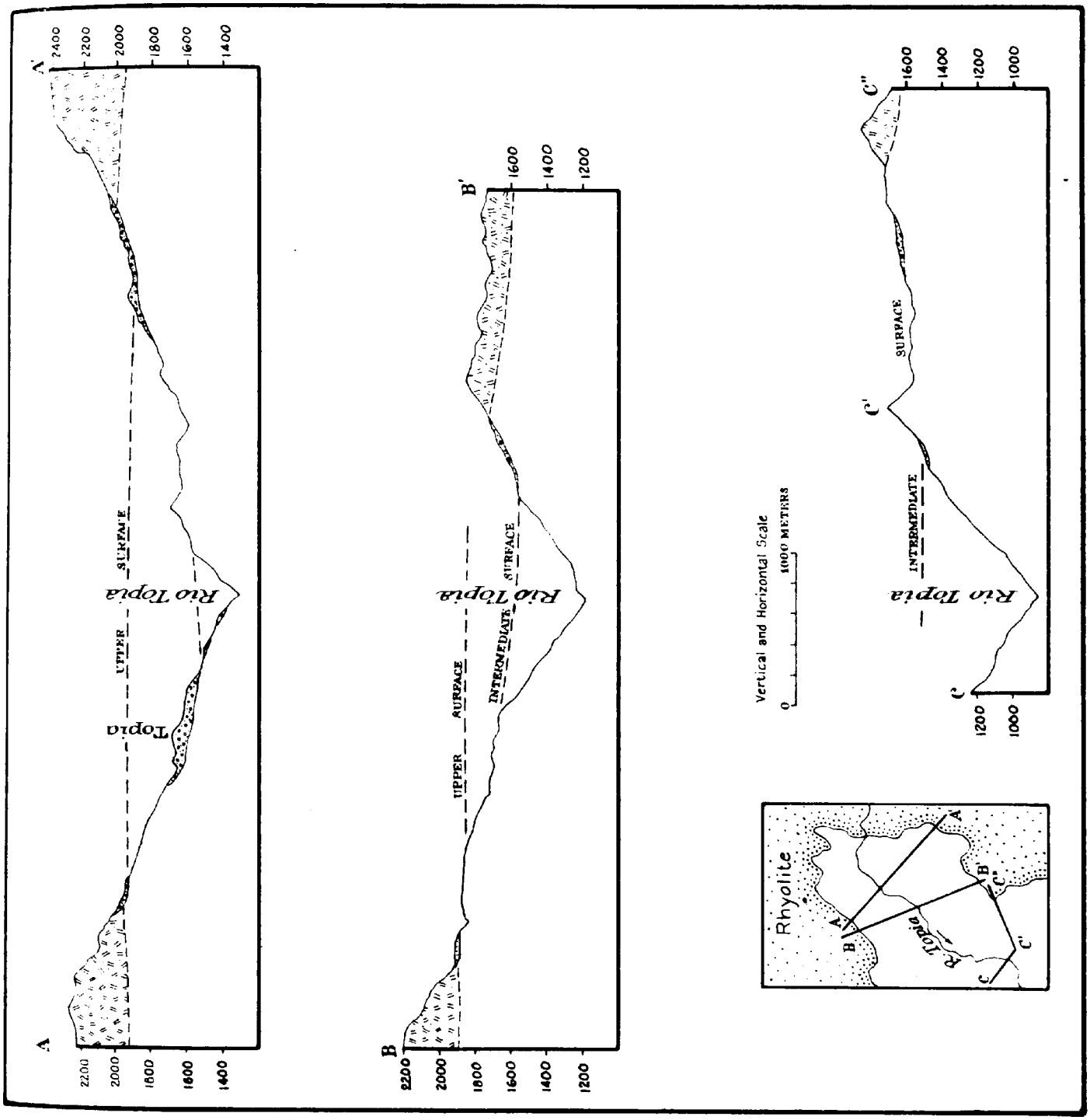
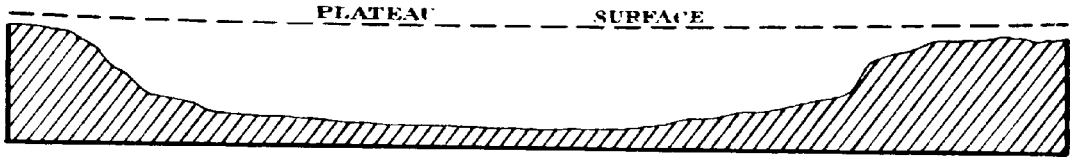
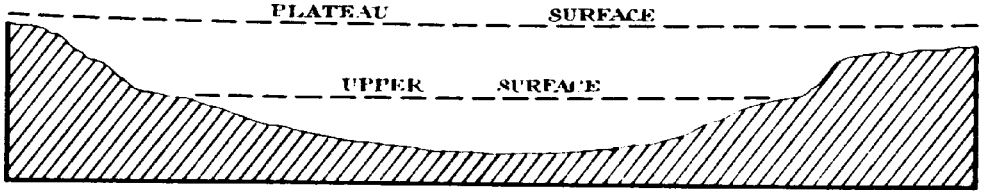


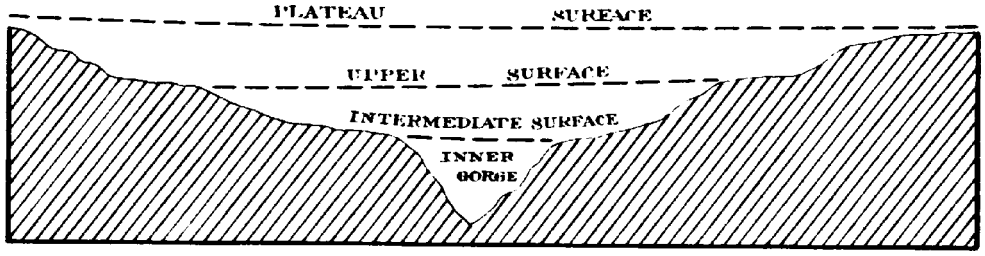
FIG.20 Profile across canyon of Rio Topia



A. 1st stage - development of upper surface



B. 2nd stage - development of intermediate surface



C. 3rd stage - development of inner gorge

FIG. 21 Idealized profiles illustrating the successive stages in the cutting of Rio Topia Canyon.

inner gorge is a relatively youthful feature and depicts the present stage of erosion. The inner gorge is believed to be the result of rejuvenation caused by very late Pliocene or Pleistocene uplift probably combined with Pleistocene climatic changes. Today all the streams have steep gradients and are still in a very active downcutting stage.

Drainage Pattern

Local Pattern. The local drainage pattern has an apparent dendritic form but close inspection shows that most of the streams have two dominant trends, northwest and northeast, corresponding to the faults in the district. Within Topia canyon, the drainage pattern on the andesitic rocks appears to be more dendritic and irregular in form because of the numerous intermittent-type consequent gullies on the steep slopes of the canyon. However, many of the major tributaries such as the two creeks on either side of Topia as well as Rio Carisso are controlled by the northwest faulting. The central part of Rio Topia has a northeast trend where it is aligned with the Molinos fault. The northwest-northeast pattern is well developed on the rhyolite plateau surface 4 kilometers north of Topia and also east and south of the canyon. The drainage pattern, where it could be checked, is structurally controlled.

Regional Pattern. The regional drainage pattern created by the major streams and tributaries in the central Sierra Madre has a rectangular form which reflects control

by northwest and northeast structural trends. It is well developed on the plateau section of the province north and south of Topia. The pattern is shown on Figure 3, the index map for the central part of the range. A good example of the structural control is present at Valle de Topia (Fig. 3) 17 kilometers northeast of Topia where a main tributary of the Sianori river follows a major northwest fault of several thousands of feet displacement (D. B. Dill, Jr., personal communication). Northwest faulting also controls the drainage of the stream in Quebrada Hondo immediately west of Chinicates ranch midway across the Sierra (Fig. 3). As in the case of the local pattern, the regional pattern reflects the major structural trends of the region.

GEOLOGIC HISTORY

The sequence of events which are recorded at Topia span a time range from late Cretaceous(?) to the present. The geologic history can be summarized as follows:

1. The oldest event of which there is a record is the deposition of sedimentary rocks which probably form the basement of the extrusive sequence. These rocks are not exposed but evidence of their existence is in the fragments of shale, siltstone, and orthoquartzite which have been brought up from unknown depth by the pebble dikes. The age of the sediments is unknown.

2. A long period of volcanic activity during which over 1500 meters of andesites was deposited is the earliest

recorded event in the exposed rocks of the region. Since the bottom of the Topia andesite is not seen, its age is tentatively considered late Cretaceous(?) to early Tertiary. The upper age limit is possibly Oligocene.

3. A period of northwest faulting and northeast fissuring was accompanied by tilting of the andesites. This was followed closely by the intrusion of the granodiorite stock, quartz monzonite plug, and quartz latite dike.

4. After the faulting and intrusion, widespread propylitic alteration occurred which in turn was followed by later quartz-sericite alteration and vein mineralization along northeast fissures.

5. A renewed period of dike intrusion was the next event. It is believed that the rhyolite dikes were intruded along the northwest faults and were then followed by the intrusion of the diabase and pebble dikes.

6. The next stage was the development of a mature surface on the andesite. The erosion took place prior to the deposition of Miocene(?) rhyolites and is therefore most likely of Oligocene or even early Miocene age. The surface formed at this time can be correlated over the Sierra Madre Occidental.

7. Deposition of over 600 meters of rhyolites occurred on the tilted, mineralized, and eroded andesites. The rhyolite volcanics are believed to be of Miocene age and can be correlated throughout the Sierra Madre. The formation of the accordant plateau erosion surface began soon after the deposition of the rhyolites.

8. Renewed faulting and slight tilting took place along the original lines of weakness. The normal faulting at this time is considered to be associated with the Pliocene uplift of the range. It was during the Pliocene uplift that the dissection of the plateau surface into the barrancas was initiated. At least two broad valley stages of erosion developed in the main canyon as a result of intermittent uplift at this time.

9. Continued uplift occurred in the very late history of the area during which the "V" shaped inner gorge was incised on the broad valley stage surfaces. The streams are still in this period of rejuvenation which may indicate that the uplift is possibly of Pleistocene age, in which case the downcutting was most likely aided by Pleistocene climatic changes.

Considerable work remains to be done before the complete history of the area can be understood. It is evident that the area has been tectonically active since the deposition of the rhyolites to the present, and the significant feature of the activity has been the repeated movement along the same trends. It is also noteworthy that all the intrusion, alteration, and mineralization occurred prior to the deposition of the Miocene(?) rhyolites. In view of the restriction of the ore deposits to the andesites in nearby districts, it is believed that the andesites are the chief ore-bearing rocks of the central Sierra Madre Occidental.

CHAPTER III

HYDROTHERMAL ALTERATION

INTRODUCTION

The detailed study of the alteration in the Topia district was undertaken to establish its relationship to the veins and its possible value as a guide in exploration for ore. Because of the similarity of the alteration at Topia to that of other districts in the Sierra Madre Occidental, the investigation adds to the understanding of the regional mineralization.

Nature of the Alteration

Propylite and quartz-sericite types of alteration prevail in the Topia district. They are also commonly associated with base or precious metal deposits occurring in other areas of Tertiary andesite. Examples include Tonopah (Spurr, 1905) and Virginia City, Nevada (Coats, 1940); the Bonanza (Burbank, 1932) and Silverton (Ransome, 1901) districts, Colorado; Brad, Rumania (Lazarevic, 1913); the Hauraki gold fields (Finlayson, 1909), New Zealand; the Tertiary deposits of Japan (Kato, 1931); and many mining camps throughout the Sierra Madre Occidental of Mexico. Detailed studies have shown that the propylitic alteration

is widespread, whereas the quartz-sericite alteration, as well as silicification, is more restricted and more closely related to the ore deposits. In some of the districts mentioned above, the argillic or alunitic types of alteration are also common.

Hydrothermal alteration has long been recognized as accompanying the process of ore deposition. Widely differing views, however, are held as to the origin of propylitic alteration and its relation to ore deposition. Some consider it a deuteric or autohydration process that occurs at the time of the consolidation of the volcanic rocks and others view it as a post-volcanic hydrothermal process preceding the deposition of ore. After a study of the field and laboratory evidence, the propylitic alteration at Topia is considered to be a post-volcanic, hydrothermal alteration preceding but related in part to ore deposition.

In a review of hydrothermal alteration, Schwartz (1939) recognizes propylitization as a definite type restricted to basic and intermediate rocks and characterized by hydrous magnesian minerals (i.e. chlorites). Additional minerals that may be present in various amounts are: epidote, carbonates (usually calcite), quartz, sericite, allophane, leucoxene, apatite, pyrite, albite, and zeolites. The major textural changes are coarsening of the groundmass and replacement of the phenocrysts with increasing intensity. In comparison with more intense types of alteration, such as sericitization and silicification, propylite contains a greater variety of minerals.

Types of Alteration

Three main types of hydrothermal alteration are distinguished in the andesitic rocks of the Topia district: the regional propylitic, the local propylitic, and the quartz-sericite types. The regional and local propylitic types are essentially similar but probably not closely related in age. Because of differences in distribution and in mineralogical details, the two are discussed separately.

The regional propylitic type is a widespread pervasive alteration that forms a large zone throughout the southwestern part of the district. (See Plate III.) It surrounds the granodiorite intrusive near Rio Pinos and affects the entire section of the Topia Andesite. The altered rocks are distinguished by their green color, produced by the abundant development of chlorites in a complex mineral assemblage typical of a mild degree of alteration. Three different mineral assemblages were recognized but not mapped; these were interpreted as representing a mineralogical zoning resulting from increased temperatures toward the granodiorite intrusive. The mineralogical assemblages in order of increasing intensity are: (1) albite-chlorite-calcite, (2) albite-chlorite-calcite-epidote, (3) albite-chlorite-epidote.

Propylitic alteration of the local type occurs in the relatively fresh andesites of the central and northern part of the district. It is restricted to narrow zones, 30 centimeters to 25 meters wide, and accompanies every

vein that occurs beyond the zone of regional propylitic alteration. The altered rock is characterized by a pronounced green color and by the albite-chlorite-calcite mineral assemblage, which is identical to the low-intensity assemblage of the regional propylitic type.

The quartz-sericite type of alteration forms a narrow band, averaging 30 to 60 centimeters in width lying between the vein and the propylitized andesite of either the regional or local type. The rock next to the vein has a grayish color and is composed of abundant quartz and sericite with some pyrite. The quartz-sericite alteration is superimposed on the propylitic type and is more closely related to the formation of the veins.

A fourth type of alteration was recognized in the andesites, but it is interpreted as deuteric in origin (Deuteric Alteration, General Geology). It occurs in the entire northern and central part of the district where the rocks are fresh in appearance. A close study of the fresh-looking, purplish-gray andesites showed that the typical propylitic assemblage of albite, chlorite, and calcite is present but restricted to the augite and plagioclase phenocrysts which are partially or wholly replaced. Because of the lack of correlation between this mild, low-grade alteration and possible controls such as surfaces of flows and faults, it was concluded that the slight changes in the otherwise fresh-looking rocks were due to deuteric activity at the time of consolidation of the lavas. Nearly all the rocks were slightly modified by the deuteric processes

before the main phase of hydrothermal activity began.

Method of Investigation

The criterion for mapping the regional propylitic alteration is the distinctive green color of the altered andesites which is in strong contrast to the normal purplish-gray fresh rock. Where the altered rocks have been weathered, the alteration zone was traced on the basis of the reddish color of the soil and rock due to the oxidation of the ferrous iron in the chlorite and pyrite. The extent of the regional propylitic alteration is shown on Plate III and all the andesite is totally altered within the area indicated on the map.

The local type of propylitic alteration associated with the veins was not mapped in areas of fresh andesite because of the narrowness of the altered zone and consequent limitations due to scale. It should be understood that the local propylitic type borders the veins that appear within the areas of fresh andesite. (See Plate III.)

The quartz-sericite zones of alteration are likewise too narrow to be shown on the map. They occur adjacent to all veins of the district.

The investigation of the alteration in the laboratory was carried out mostly by means of the petrographic microscope using thin sections and oil immersion methods. The chlorite minerals were studied with little success, because of the difficulty of obtaining pure samples and also

because of the lack of information concerning this group of minerals. The powder x-ray technique could be applied only in a few cases to the chlorites. Random and selective sampling was employed in obtaining specimens of the various types of altered rock. A series of samples was taken at various intervals at right angles to the San Miguel vein and these were studied by means of thin sections and chemical analyses. In the petrographic study of the alteration, 90 thin sections were used.

MINERALOGY OF THE ALTERED ROCKS

General Features

A distinctive set of minerals is found in the altered rocks at Topia. Chlorite, albite, calcite, and epidote are characteristic of the propylitic type of alteration (regional and local); quartz, sericite, and hydromica are characteristic of the quartz-sericite type. Minor alteration products include allophane, apatite, leucoxene, magnetite, rutile, and pyrite. The kaolin and montmorillonite mineral groups, which are so characteristic of the argillic type of alteration of other districts such as at Butte and East Tintic, do not occur in the altered rocks of the Topia district.

As is common to all detailed alteration studies, one of the problems is the proper identification of the alteration minerals. Thin sections, which were of great

aid in the study of the age relations of the minerals, were not entirely satisfactory for the identification of some minerals, especially those of the chlorite group. Wherever possible, the oil immersion technique was used to verify the thin section identification. The method of x-ray analysis could be used only a few times because it was difficult to obtain large enough amounts of the pure mineral.

The Alteration Minerals

Chlorite Group and Related Minerals. The most important and widespread minerals found in the propylitized rocks are members of the chlorite group and others of similar character. In the course of the investigation, it soon became evident that several varieties of chloritic minerals are present, but the available information is inadequate for their precise determination. Table I summarizes the optical properties of the principal chloritic minerals noted in the present investigation.

All the alteration minerals which give a green color whether faint or strong have been considered to be chlorites or closely related chlorite-like minerals in the course of this study. The common characteristics of the group, in addition to the color, are positive elongation and parallel extinction. Only in a few thin sections was a definite pennine type of chlorite with negative elongation and tobacco brown or blue anomalous interference colors recognized. Some of the chlorites have all the properties

of pennine and prochlorite except for elongation. Where it was possible to obtain the optical sign the chlorites were negative with a small 2V. The range in the maximum and minimum indices of refraction is very great--from 1.572 to 1.646.

It is possible to divide the chloritic minerals into two groups on the basis of their birefringence. Most of the chlorites belong to the low-birefringent group in which the birefringence ranges from .003 to .010. In the high-birefringent chlorites, which are not very abundant, the range is .020 to .021. The low-birefringent chlorites are widespread and are found in the groundmass or replacing former mafic phenocrysts. The pennine type, distinctive because of the anomalous interference colors, is generally restricted to rocks of the high intensity zone of regional propylitic alteration. The high-birefringent variety occurs as halos (Fig. 23A) around fragments of regionally propylitized tuffs or as veinlets or aggregates in the local propylitization. In the few places where noted in local propylitic zones, it was seen veining or replacing the low-birefringent chlorites indicating that it may have formed later in the propylitic sequence.

An x-ray power pattern was obtained from the high-birefringent chlorite whose indices of refraction were 1.582 to 1.603 (no. 11 in Table I) and it was found that it had a typical one layer mica type structure (A. A. Levinson, personal communication). The spacings were similar to those published in the ASTM cards for celadonite.

TABLE I

OPTICAL PROPERTIES OF CHLORITIC AND RELATED MINERALS IN ALTERED ANDESITES, TOPIA, DURANGO, MEXICO.

Occurrence	Color	Pleo.	Extinc.	Elong.	Sign	General Index $\frac{\alpha+\beta+\gamma}{3}$	Biref.	Name
1. Deuteric	pale green		Parallel	Positive	Negative	1.572---1.579	.009	Antigorite?
2. Regional propylitic	waxey pale green		" "	"	"	1.574---1.581	.007	Delessite?
3. " "	"		" "	"	"	1.571---1.575	.004	
4. Local propylitic	dull gray green	faint	" "	"	"	1.578---1.582	.004	
5. " "	pale green		" "	"	?	1.578---1.587	.009	
6. " "	bright green	faint	" "	"	?	1.581---1.591	.010	
7. " "	dark green		" "	"	?	1.590---1.595	.005	
8. Regional propylitic	olive green	green to yellow-green	" "	"	Negative	1.601---1.605	.004	Prochlorite?
9. Local propylitic	medium green		" "	"	?	1.600---1.605	.005	
10." "	gray green		" "	"	?	1.604---1.608	.004	
11." "	bright green	blue-green to yel-grn.	" "	"	Negative	1.582---1.603	.021	Celadonite?
12." "	dark green	" "	" "	"	?	1.582---1.602	.020	" "
13. Regional propylitic	pale green	faint	" "	"	?	1.614---1.618	.004	
14." "	pale green	faint	" "	"	?	1.618---1.622	.004	
15. Local propylitic	dull green		" "	"	?	1.642---1.646	.004	

Although optical properties do not agree with the published data on celadonite ($N_x - N_z = 1.608 - 1.638$, Winchell, 1951) the high-birefringent material is tentatively called celadonite.

Enough of the waxy pale green chlorite (no. 2, Table I) was obtained to study it by means of an x-ray powder photograph. The x-ray pattern is almost identical to the high-birefringent celadonite type, but the lines are of much greater intensity. This may indicate that the low-birefringent type is structurally similar to the celadonite and that the higher intensity of the lines is due to its lower content of iron. On the basis of the intensity variation and the optical properties, it is believed that the low-birefringent chlorites are high in magnesium and low in iron.

The benzidine stain test was used on the low-birefringent chlorites and on many highly altered propylitic rocks, and in most cases a strong ink-blue positive reaction was obtained. The blue reaction, however, is considered to be a test for the montmorillonite group of clay minerals (Hambleton and Dodd, 1953, pp. 139-146). Therefore the presence of the green-colored, iron-bearing montmorillonite, nontronite, was suspected in the propylitized rocks. The possibility of nontronite was ruled out, however, when the low-birefringent chlorite (no. 2, Table I) gave an intense blue reaction to benzidine and the x-ray powder pattern indicated that it definitely was not a montmorillonite clay (G. T. Faust, personal communication).

The conclusion was reached that the micaceous chlorites give a positive reaction in the benzidine stain test.

The investigation of the chloritic minerals indicates their complexity. From the study of the Topia chlorites it is evident that several varieties occur in the altered rocks, and the word chlorite, when used in connection with propylitic alteration elsewhere, probably covers a complex suite of green, iron- and magnesia-rich hydrous silicates.

It is very possible that if means of differentiating the chlorites were available, additional information of genetic significance could be obtained. The existence of different varieties of chlorite may be related to factors such as the composition of the original minerals, intensity conditions, and variations in the solutions. At Topia not enough is known about the chlorites or their distribution to indicate how such factors could apply. However Price (1953, p. 1464), in a recent study of alteration at Noranda, Quebec, has shown that a late high-magnesian alteration in which many varieties of chlorite were formed is closely associated with copper mineralization. Recognition of the variations within the chlorites has been of value in finding ore. Lindgren (1926, pp. 135-144) describes high iron-bearing chlorites as being closely related to the tin ores at Caracoles, Bolivia.

Albite. Albite is characteristic of all the propylitized rocks. The indices of refraction are between

1.530 (N_2) and 1.540 (N_1) which indicates that the composition of the albite is Ab_{94}. In places where the fresh andesites show very little deuteric alteration, the original plagioclase is andesine with a composition Ab_{65}-Ab_{55}. The replacement of the andesine by albite was generally controlled by the cleavage and twinning of the crystals. However, both twinned and untwinned albite occur in the propylitically altered rocks. A very consistent feature of the propylitization is the attack on albite in varying degrees by allophane, chlorite, calcite, epidote, sericite, and hydromica. This indicates that the albite is early in age and that the sodium ion tends to be removed with an increase in the degree of alteration.

Calcite. Calcite is a very common alteration product accompanying propylitic alteration of the local type and the low and moderate intensity zones of the regional type. It also occurs as a late gangue mineral in the veins. In propylitized rocks, calcite is most noticeable where it replaces albite along cleavage planes or grain boundaries. It also occurs as small irregular grains throughout the groundmass. The calcite replaces the albite and low-birefringent chlorites and is considered later in age (Figs. 23, 25). The mineral was checked by oil immersion methods and was definitely identified as calcite. No dolomites or other carbonates have been recognized.

Epidote. All the epidote in the Topia area is restricted to the high and moderate intensity zones of the regional type of propylitic alteration. The epidote has a

distinctive yellow-green color and is the low-iron variety. The mineral occurs as grains, granular aggregates and minute veinlets throughout the phenocrysts and groundmass of the propylitized rocks (Figs. 26, 27). A few grains of zoisite are associated with the epidote in a few specimens. The epidote readily replaces the albitized and chloritized phenocrysts and is definitely later than the albite and chlorite (Figs. 26, 27). However its relation to calcite is not clear. Where both minerals coexist in the moderate intensity zone they appear to be the same age.

Sericite-Hydromica. Sericite and hydromica are the most abundant and characteristic minerals of the quartz-sericite alteration adjacent to the veins. Both are found in small amount in the propylitized rocks occurring as scattered flakes in the phenocrysts and groundmass.

The hydromica, which is far more common than the sericite, can readily be recognized by its lower birefringence. Both of these micaceous minerals occur as flaky aggregates or minute veinlets throughout the groundmass and phenocrysts of the quartz-sericite type of altered rock. They appear to be among the latest alteration products.

Quartz. Quartz, a common mineral of the altered rocks, occurs in several ways. A very small amount of quartz is usually present as an accessory mineral in the propylitized rocks, where it forms small clear crystals

in chloritized mafics or calcitized phenocrysts. Quartz is most abundant in the quartz-sericite bands adjacent to the veins where it represents partial silicification of the walls. Here the quartz is intimately mixed with sericite and hydromica in a mosaic-like texture constituting the groundmass of the rock. The fine-grained quartz of the groundmass is irregular in shape and very cloudy due to minute inclusions of allophane which give the quartz a brownish cast. The former mafic and plagioclase phenocrysts are usually wholly or partially replaced by somewhat clearer and coarser quartz.

Very commonly veinlets of clear, white, coarse quartz are found cutting across the partially silicified groundmass. The quartz in the veinlets is generally associated with scattered grains of pyrite. This late quartz penetrating into the walls is interpreted as part of the ore-forming stage of mineralization.

Pyrite. Although pyrite is not an abundant mineral, its presence in the altered rocks is significant. It is found in regional, local, and quartz-sericite types of alteration as well as in the veins associated with the ore minerals.

Pyrite is most closely related to the quartz-sericite alteration. The pyrite forms simple or modified cubes rarely exceeding one millimeter in size. It is disseminated throughout the rock. The amount of pyrite in the wall rock diminishes rapidly away from the vein, but in

many places the pyrite extends beyond the quartz-sericite zone into the propylitized rock. This can be seen in several of the mines in the main part of the district where in all cases the disseminated pyrite is most abundant close to the veins. Pyrite was not found in the fresh rocks outside of the alteration envelope surrounding the veins.

Pyrite also occurs in the regionally propylitized rocks. Several thin sections show a minor amount of pyrite apparently as an accessory mineral. On the whole it appears to be somewhat more common in the high intensity zone of the regional alteration than it does in the moderate and low intensity zones. Pyrite is also present in the areas immediately surrounding the granodiorite stock and the quartz monzonite porphyry. This may indicate that it is also closely related to the intrusives.

Accessory Minerals. A number of minerals which include allophane, apatite, leucoxene, rutile, and magnetite are also products of hydrothermal alteration at Topia. Because these minerals make up only a very small portion of the altered rocks, they have been classified as accessories.

Allophane, an amorphous mineral, is present in all of the altered rocks of the district. It occurs as dusty brown specks or blebs in the albite and quartz as well as the groundmass. It is a common mineral and where abundant it gives thin sections a brownish cast. Because of its oval

shape, minute size, pinkish-brown color, and extremely low index (ca. 1.48), the mineral is tentatively identified as allophane. Since it is present in all three types of alteration, the overall significance of allophane is difficult to determine. It is possible that allophane either forms under a variety of conditions or much of it that is seen may be present in later stages as a relict of an earlier alteration. There is a possibility also that what is tentatively identified as allophane may represent a different type of low-index amorphous mineral such as kimolite which formed at different stages. The true significance of allophane is not known although it or similar amorphous minerals may represent an incipient stage of alteration. Similar occurrences of allophane with nearly all stages of alteration have been noted in the East Tintic District by Lovering (1949, pp. 35-41).

Apatite, which is common to most of the altered rocks, occurs as tiny rods or lath-shaped crystals generally in the albitized phenocrysts and somewhat less in the sericite, hydromica, and quartz. A minor amount of apatite is also present in the fresh andesites as a primary accessory mineral. It is possible that the apatite seen in the altered rocks represents relict primary material.

Leucoxene is widespread in all the altered rocks of the district. Although generally well scattered throughout the rock as small irregular clusters, in many places it is closely associated with magnetite crystals and former augite phenocrysts. Both may have served as a source of titanium

for the formation of the leucoxene.

Rutile, present in small amount, is always associated with leucoxene, from which it seems to be derived. The rutile generally occurs as small rod-shaped or tiny sagenitic needles in the leucoxene.

Most of the magnetite is a primary accessory mineral in the fresh andesitic rocks, but a small amount of it forms as a by-product in the chloritization of the mafic minerals. Some of the secondary magnetite occurs along the borders of chloritized augite as tiny black crystals which distinctly outline the former shape of the augite. The secondary magnetite is commonly altered to leucoxene, pyrite or limonite.

DESCRIPTION OF THE ALTERED ROCKS

Regional Propylitic Type

General Features. The accepted definition of propylitic rocks as being altered basic or intermediate volcanic rocks of green color containing chlorite, epidote, albite, and calcite describes the altered andesites of Topia. The regional type of propylitic alteration resembles the widespread pervasive propylitization in many other districts, such as Tonopah (Spurr, 1905) and Virginia City, Nevada (Coats, 1940). The red soils derived from the weathered, propylitized andesites are visible throughout an area several miles in width when looking southwest down

the canyon of Rio Topia from any high vantage point (Fig. 22). This impressive view emphasizes the regional character of the alteration.

The favorable geologic setting of the Topia district offered an excellent opportunity for a study of widespread alteration of this type. As a result of the unusual depth of Rio Topia canyon, the geologic details are exposed in three dimensions. By mapping the several andesites as stratigraphic units, it was possible to note the relation of the alteration to the rocks, structure, and ore deposits. It is concluded that the propylitization at Topia represents an early barren phase of post-volcanic hydrothemmal activity.

Distribution. The extent of the regional type of propylitic alteration is indicated on Plate III. Of a total area of 40 square kilometers (15 square miles) of exposed andesites, 19.5 square kilometers (7.5 square miles) or 48% of the area is propylitically altered. The zone of alteration extends beyond the mapped area as a large halo about the granodiorite intrusive, and it is estimated that the total area of propylitic alteration is at least 78 square kilometers. (See Fig. 22 and Plate III.)

The regional alteration is more intense in the southwestern corner of the district, where all the rocks have been affected. The alteration gradually weakens to the northeast, and in the central part of the district between the Ojeda and Victoria fault zones, it terminates

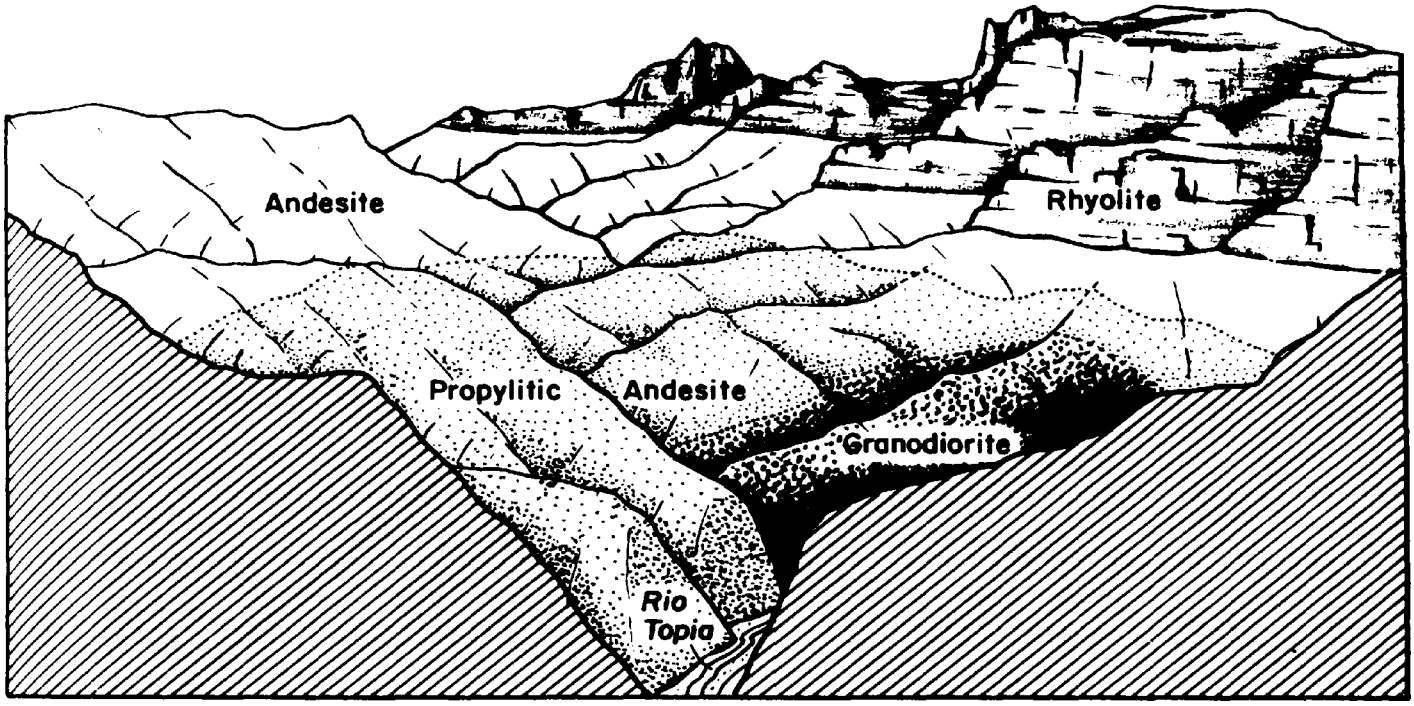


Fig. 22 Looking southwest down the canyon of Rio Topia at the highly dissected topography of the barranca section. The massive cliffs of rhyolite represent the plateau section. The propylitized andesites surround the granodiorite.

in an irregular finger-like pattern (Plate III).

The distribution of the regional alteration clearly indicates that it is of post-volcanic age and has been controlled by structure and lithology. The importance of structure can be seen, for example, in the bottom of the canyon of Rio Topia where all the joints and fractures within the area of propylitization are coated with epidote. The pre-mineral Ojeda fault zone, however, had a barrier effect on the movement of the solutions. The lavas of the basal Santa Ana formation northeast of the fault are fresh, whereas the same lavas southwest of the fault are completely propylitized.

The lithologic control is best demonstrated at the margin of the altered zone between the Ojeda and Carisso faults. Here the alteration is interfingered with certain units of the andesites. The tuffaceous units are highly altered whereas the lavas both above and below the tuffs are fresh. The contrast is due to the greater permeability of the andesite tuffs, as they average 10% porosity in comparison to the andesite lavas which average 3%. The greater porosity of the tuff explains the extension of the alteration for a considerable distance northeast of the center of hydrothermal activity.

The regional propylitization is concentrated about the post-andesite granodiorite intrusive in the southwest corner of the district. The altered zone thus forms a large dome-like halo that surrounds the intrusive on all sides (Fig. 22). This pattern of distribution suggests that

the intrusive is the fundamental regional control.

General Description. The andesitic lava is the principal rock type involved in the alteration whether it occurs as a true flow or as fragments of varying size in the agglomerates and tuffs. The typical unaltered lava is a purple-gray porphyry containing phenocrysts of andesine and augite in a microcrystalline groundmass consisting of microlites of andesine and granules of augite or magnetite. Apatite, magnetite, and rare zircon are the chief accessories.

The regionally altered andesites have a bleached appearance and are characterized by a grayish-green color with some local variation. The altered tuff or agglomerate from the outer fringe zone has a lighter green color and is more bleached than the altered lava closer to the granodiorite intrusive. The lavas and tuffs in the southwest part of the district near the intrusive generally have a greenish-yellow tint due to the abundance of epidote, which occurs irregularly throughout the rocks or in local concentrations as clusters or coatings on joint surfaces. The alteration does not destroy the texture of the rocks entirely, and the altered tuffs and lavas are readily distinguished.

On weathering, the propylitically altered rocks break down into a limonite-stained red soil which covers the areas of alteration. The zones of red soil are usually

called "colorados" in Mexico and are common in many mineralized areas.

In studying the rocks under the microscope it was noted that specimens from different parts of the regional alteration zone showed variations in the mineral assemblages. The variations are believed to represent a mineralogic intensity zoning related to the granodiorite intrusive. Three assemblages were distinguished:

1. Low intensity type -- albite-chlorite-calcite
2. Moderate intensity type -- albite-chlorite-calcite-epidote
3. High intensity type -- albite-chlorite-epidote.

Petrographic Description. The regionally propylitized andesites consist principally of low-birefringent chlorite, albite, calcite, and epidote. The alteration at Topia is thus very similar to the type area of propylitic alteration at the Comstock Lode, Nevada (Coates, 1940). The andesine phenocrysts of all sizes are converted into albite which in turn is partially or wholly replaced by allophane, epidote, calcite, and flakes of sericite or hydromica. The albite occurs either with the typical twinning or without twin lamellae. The augite is replaced by low-birefringent chlorite which in places is associated with some later calcite, epidote, quartz, magnetite, leucoxene, or pyrite. Very commonly a halo or rim of magnetite crystals surrounds the altered augite phenocrysts. The groundmass is generally an aggregate of low-birefringent



Figure 23A--Andesite tuff, low intensity regional propylitic alteration, from locality 1 1/4 kilometers southwest of Topia. The fragmental nature of the rock is shown. Opaque areas are leucoxene. Plane polarized light. X 65.

Figure 23B--Same as A. The dark areas are low-birefringent chlorite. Narrow shreds of high-birefringent chlorite surround some of the fragments. White areas are calcite. Crossed nicols. X 65.

Figure 24-- Andesite lava, low intensity regional propylitic alteration from Los Hornos Ridge 1 1/4 kilometers south of Topia. Small areas of high-birefringent calcite partially replace the large albitized plagioclase phenocryst (left). The phenocryst in the upper right corner is completely replaced by calcite. A central area of fibrous, radiating, green chlorite replaces part of the groundmass. Crossed nicols. X 26.

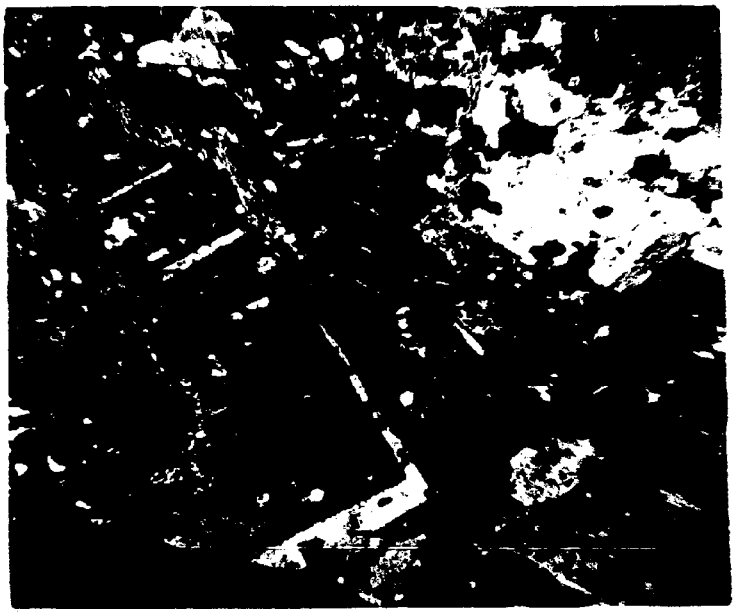
Figure 25-- Andesite lava, moderate intensity regional propylitic alteration from Rio Topia Canyon 2 1/2 kilometers southwest of Topia. Calcite and small grains of epidote replace the large albitized phenocryst in the lower right corner. Epidote replaces pennine along cleavage in a former mafic (right center). The groundmass consists of epidote, chlorite, calcite, and albite. Crossed nicols. X 35.



23-A



23-B



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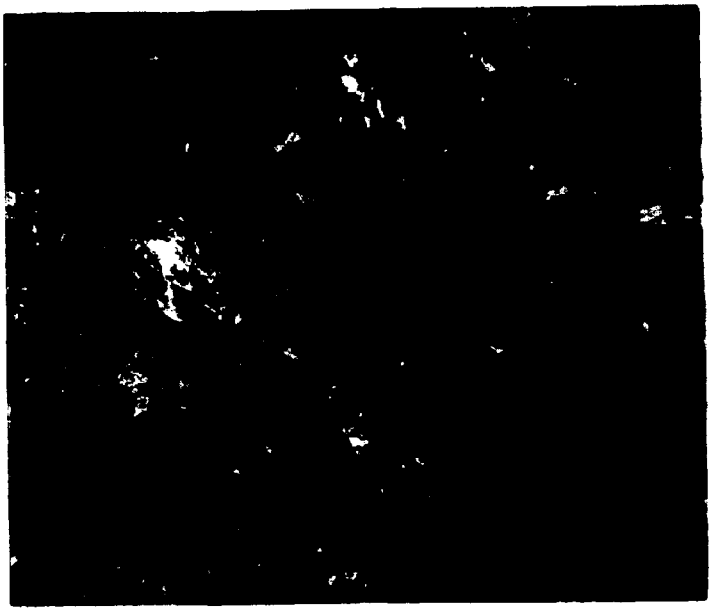

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In specimens that are slightly altered, the replacement of the phenocrysts by albite and chlorite represents most of the alteration.

Intensity Zoning. The low intensity type of alteration is characterized by the presence of calcite and by the complete absence of epidote (Fig. 24). A distinctive mosaic-like texture is formed by the halos of high-birefringent chlorite surrounding the various rock fragments (Fig. 23, A and B). On weathering the limonite staining is concentrated in the halos. Albite does not everywhere completely replace the andesine phenocrysts. Calcite is the dominant mineral in the alteration of the feldspars and groundmass.

This type of alteration is limited to the tuffs and agglomerates of the outer fringe zone at elevations above 1400 meters east of the Ojeda fault. The rocks of this area are characterized by the albite-chlorite-calcite assemblage. The moderate intensity type of alteration is distinguished by the appearance of epidote which occurs as small granules with the calcite and chlorite of the groundmass and phenocrysts (Fig. 25). The plagioclase phenocrysts are completely albitized and a deep blue-green, low-birefringent chlorite of the pennine variety has replaced the augite phenocrysts.

This type of alteration is found in the tuffs and lavas that occur in the canyon of Rio Topia between the elevations of 1400 and 1000 meters east of the Ojeda fault

and that are still within the outer fringe zone. The alteration is characterized by the albite-chlorite-calcite-epidote assemblage.

The high intensity type of alteration is characterized by the abundance of epidote and rare traces of calcite The epidote occurs as veinlets or as irregularly scattered grains throughout the groundmass and phenocrysts (Figs. 26, 27). The plagioclase phenocrysts are completely albitized and the pennine type of chlorite and other low-birefringent chlorites replace the groundmass and phenocrysts. Minute needles of rutile can be seen in the patches of leucoxene. The abundance of epidote varies from specimen to specimen; in some places clusters and local concentrations of epidote are common.

Andesites showing alteration of the high intensity type are found below the 1000 meter elevation west of the Ojeda fault close to the granodiorite and well inside the outer fringe zone. The rocks of this area are represented by an albite-chlorite-epidote assemblage. Because of the abundance of epidote, it is the only intensity type which can readily be recognized megascopically.

The location of the various specimens examined suggests that the variation in the intensity of alteration is related principally to the distance from the granodiorite intrusive. The disappearance of calcite and the appearance of epidote as the intrusive is approached is believed to reflect an increase in temperature and in turn constitutes a definite mineralogic zoning. Epidote is considered an

indicator of higher temperature than calcite which prevails at a greater distance from the granodiorite. The increase in the intensity of propylitic alteration towards the intrusive emphasizes that the center of hydrothermal activity was in the area of the granodiorite.

Relation to Ore Deposits. The regional type of propylitic alteration is related to the ore deposits only in a general way. It is widespread in nature and independent of the vein fractures Alteration of the quartz-sericite type, on the other hand, is very closely related to the veins and is of later age.

Veins that occur in the region of widespread propylitic alteration are bordered by a narrow zone of the quartz-sericite type. However, veins occuring in fresh andesites are economically more important. These veins are likewise bordered by a band of quartz-sericite alteration which in turn is separated from the fresh rock by a narrow zone of propylitic alteration. This is referred to as alteration of the local type.

Local Propylitic Alteration

The local type of propylitic alteration resembles the low intensity regional type, but it is restricted to areas of unaltered andesite where it forms narrow zones parallel with the veins. This permits a detailed study of the alteration and its relation to the ore deposits.

Distribution. A zone of propylitic andesite borders every vein in the district beyond the regional propylitic zone. This alteration zone which ranges from 30 centimeters to 25 meters in width is too narrow to be shown on the accompanying maps.

The main control for the local type of propylitic alteration was the northeast-trending system of fissures and faults, many of which were mineralized to form veins. This control is clearly demonstrated, for example, by the La Perla vein on Tepalcates ridge (Fig. 34). The alteration parallels the vein throughout its length and also accompanies each of the small branch veins.

The La Perla vein was mapped in detail to see if the extent of the alteration could be correlated with the intensity of mineralization as expressed by the width of the vein, but it was concluded that the physical condition of the wall rock exerted the major influence. The width of the alteration zone is primarily dependent on the amount of open space available in the form of brecciation, joints, and fissures. Where the branch veins are numerous, the alteration zone widens condiderably. In the northeast corner of the area the alteration spreads out, not only because of the abundance of many narrow stringers but also because an extremely coarse bed of tuff overlying a porous upper surface of a lava flow has provided a permeable channelway (Fig. 34).

Petrographic Description. At the border of the

Figure 26--Andesite lava, high intensity regional propylitic alteration from bottom of Rio Topia Canyon 3 kilometers southwest of Topia. Epidote occurs as grains throughout groundmass. It partially replaces a large albitized phenocryst (top center) and a chloritized mafic (bottom center) along cleavage. Crossed nicols. X 35.

Figure 27--Andesite lava, high intensity regional propylitic alteration from bottom of Rio Topia Canyon 3 kilometers southwest of Topia. Coarse-grained epidote replaces albitized phenocryst in lower right corner. A former mafic (left center) is replaced by chlorite (dark) which in turn is veined by epidote (light). Crossed nicols. X 65.

Figure 28--Andesite lava, 5 meters south of Cantaranas vein, San Miguel mine. Phenocrysts of plagioclase are albitized and partially replaced by calcite. Chlorite replaces former mafic (center) and occurs in slightly altered groundmass. Crossed nicols. X 65.

Figure 29--Andesite lava, 2 meters south of Cantaranas vein, San Miguel mine. Calcite and chlorite are abundant and are disseminated throughout the groundmass and albitized phenocrysts. A former mafic (left) has an opaque rectangular outline of magnetite and leucoxene and is filled with calcite and chlorite. Crossed nicols. X 65.



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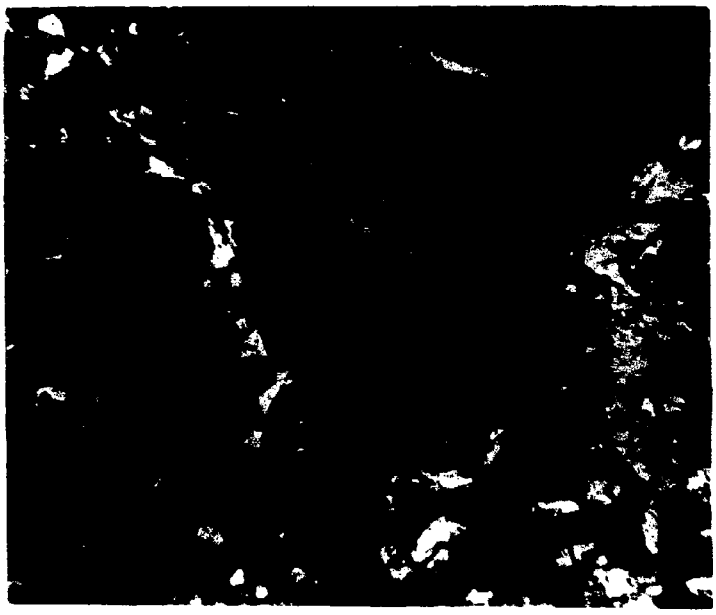

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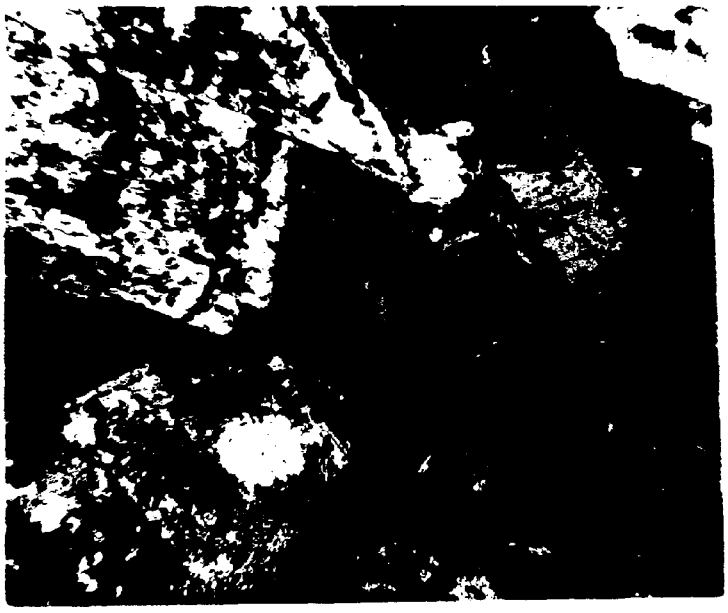

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Figure 30--Andesite lava, 65 centimeters south of Cantaranas vein. San Miguel mine. High-birefringent areas and veinlets of sericite replace the low-birefringent chloritized groundmass. Crossed nicols. X 65.

Figure 31--Andesite lava, adjacent to south side of Cantaranas vein, San Miguel mine. A groundmass consisting of fine-grained replacement quartz, hydromica, and pyrite (opaque) surrounds a central area of sericite. Crossed nicols. X 65.

Figure 32--Andesite lava, adjacent to Las Animas vein, Olivia mine. Wall rock (left) has been completely replaced with fine-grained quartz where it borders the coarse quartz of vein (right). Crossed nicols. X 65.



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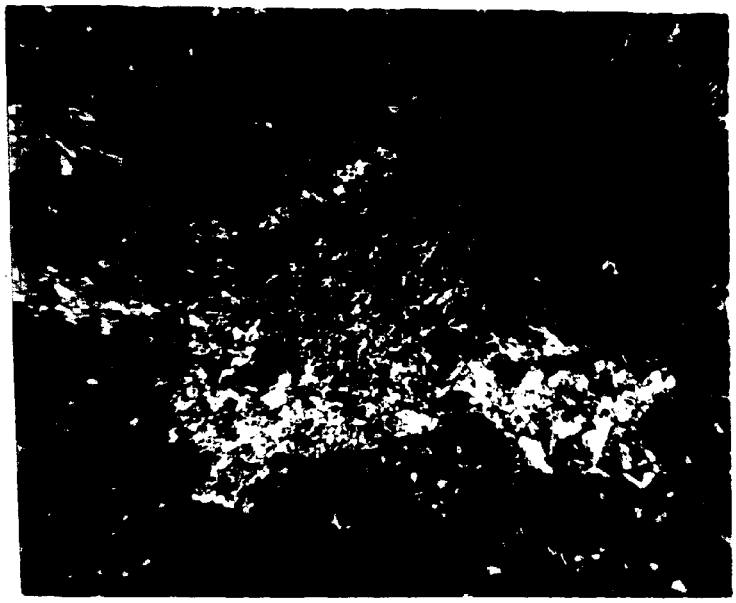

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alteration zone, the first sign of hydrothermal attack is the bleached appearance of the groundmass together with the presence of white, opaque, feldspar phenocrysts and chloritized mafic minerals. The color of the groundmass gradually changes into a mixture of green and purple and finally into a light grayish-green near the vein. Because of the abundance of calcite, the green rock commonly has a white mottled appearance. As the intensity of the alteration increases the rock becomes softer and more porous.

The progressive increase in the intensity of the alteration toward the vein is clearly demonstrated by the specimens of altered andesite bordering the San Miguel vein (Fig. 37). The specimens were taken at intervals at right angles to the vein and across both the zones of propylitic and quartz-sericite alteration. The specimens were also used in a chemical study of the altered rocks. The propylitization gradually increases in intensity until it reaches a narrow band of superimposed quartz-sericite alteration which is adjacent to the vein.

At a distance of 5 meters from the vein at the outer boundary of the alteration zone, the rock is slightly bleached. As noted in thin section, the andesine phenocrysts have been albitized and coated with a few dusty, pinkish-brown specks of allophane. A small amount of calcite and a few shreds of hydromica occur in the albitized phenocrysts (Fig. 28). The augite phenocrysts are completely changed to low-birefringent chlorite with some magnetite and leucoxene. Some of the larger chlorite areas

show a small amount of quartz. The alteration present in the fringe zone is very selective and is confined almost entirely to the phenocrysts. In the groundmass there is little alteration except for the albitization of the microlitic feldspar crystals. In summary, albite, chlorite, and a minor amount of calcite are the principal alteration products of the fringe zone.

At a distance of 2 meters from the vein the rock still retains a purplish color although it is severely bleached and shows several patches of green. The albitized phenocrysts are rich in allophane and partly replaced by calcite (Fig. 29). The augite phenocrysts, now replaced by low-birefringent chlorite, are surrounded by small amounts of magnetite, leucoxene and rutile. The groundmass is partially replaced by a mixture of albitized microlites, calcite, low-birefringent chlorite and flakes of hydromica. Hydromica is fairly common throughout the slide. It is not restricted to any one mineral, but occurs in the groundmass, albite and chloritized mafics. The greater degree of alteration is indicated by the partial replacement of the albite and altered groundmass by calcite.

At a distance of 65 centimeters from the vein the andesite has been altered into a light grayish-green, porous-looking rock. The albite phenocrysts are almost entirely altered to an aggregate of sericite-hydromica and calcite. The gmoundmass is a mixture of low-birefringent chlorite, hydromica and sericite, with some calcite, leucoxene, and pyrite. Chlorite, especially abundant in the

groundmass as rosettes or broad banded masses, is replaced and veined by sericite (Fig. 30). Sericite and hydromica are far more common than calcite, which indicates that at this point a transition from the propylitic alteration to the quartz-sericite type of alteration is taking place. Closer to the vein the quartz-sericite type of alteration prevails.

Thin sections made from diamond drill cores and mine samples representing the propylitic zone of many veins throughout the district were studied and showed similar mineralogical and textural changes. In some specimens a high-birefringent celadonite replaces the low-birefringent chlorite. Weathered specimens show the same features as the unweathered specimens with the exception that all the calcite has been leached out and the rock is stained with limonite. No epidote was recognized in any of the specimens representing the propylitic alteration next to the veins.

The local type propylitic alteration exhibits a definite sequence of the alteration products. Albitization of the andesine and chloritization of the augite are the characteristic changes of the fringe area. The next change is the appearance of calcite and the formation of low-birefringent chlorite in the groundmass. A minor amount of secondary quartz is formed with the calcite and chlorite. The age of the sericite-hydromica was difficult to establish but it appears to be later than the calcite and chlorite. Allophane is present in all the propylitically

altered rocks and usually occurs in the albite with increasing abundance as the intensity of the propylitization increases. It is believed that its nature of occurrence indicates that allophane or allophane-type minerals may form throughout the period of alteration. (See Allophane.) As a rule the alteration of the phenocrysts precedes the alteration of the groundmass. The age relations and mineral assemblage found in the local type of alteration are the same as those characteristic of the low intensity zone of the regionally altered rocks.

Relation to Ore Deposits. The propylitic alteration preceded the quartz-sericite type of alteration and the formation of the veins This conclusion is based on the following evidence: (1) the petrographic evidence shows that the quartz-sericite alteration is superimposed on the propylitic type; (2) the close control of the alteration by the fissures, with the propylitization always on the wall rock side of the quartz-sericite alteration. Although every vein is accompanied by a propylitic zone, a few fissures that show a narrow band of propylitization are unmineralized. Thus the mineralizing solutions did not follow all the earlier channelways and the veins are somewhat more restricted than the zones of local propylitic alteration. However, its constant presence along the veins indicates that it is probably closely related to the later quartz-sericite alteration and vein mineralization. On the whole the presence of propylitically altered andesite is a good general

guide to ore.

Quartz-Sericite Type

General Features. The quartz-sericite type of alteration has a direct association with the ore deposits. Although it is adjacent to the vein, it is not easily recognized in the field because of the dark greenish-gray appearance of the altered rock which offers only a slight color contrast with the propylitic alteration. The abundance of disseminated pyrite and partial silicification are better criteria than color for the recognition of this zone. The quartz-sericite alteration is superimposed on the earlier propylitic alteration. It is a very common alteration found in many mining districts, where it is generally late in age and closely associated with ore deposition.

Distribution and Controls. The quartz-sericite type of alteration affects a smaller volume of rock than even the local type of propylitic alteration. It occurs exclusively as a narrow zone 30 to 60 centimeters wide, immediately adjacent to the veins. In the areas of fresh andesite it is bordered in turn, by a narrow zone of propylitized andesite. Both types of alteration were thus controlled by the same northeast fissure system that controlled the veins (Plate III). The quartz-sericite type is also associated with the veins that occur in the area of regional propylitic alteration. The presence of a sericitized and silicified envelope parallel with every vein in the district

led to the conclusion that the alteration was produced by the solutions closely related to those that formed the veins.

Another factor in the alteration and in the vein formation is the high degree of porosity produced by the earlier propylitization. This increased the permeability of the channelway and thus promoted subsequent flow and vein mineralization.

Petrographic Description. A microscopic study was made of specimens from the quartz-sericite zone of numerous veins of the district. A progressive change in the character of the alteration as the vein is approached is expressed by an increase in quartz and a corresponding decrease in the sericite.

One of the specimens collected for a chemical study of the alteration along the San Miguel vein is representative of the quartz-sericite alteration zone. For a distance of 10 centimeters from the vein, the rock is completely altered but the original porphyritic texture is still discernible under the microscope. The entire groundmass is flooded by fine-grained replacement quartz which contains a considerable amount of allophane. The former albitized phenocrysts are completely altered into fine-grained sericite and hydromica with some quartz and residual apatite. Leucoxene, with some associated rutile and abundant cubic pyrite, is scattered throughout the rock. A small amount of residual low-birefringent chlorite, previously developed in the propylitic zone, is replaced by sericite and quartz

(Fig. 31). Sericite and quartz make up 90% of the mineral content of the altered rock.

Although specimens from the quartz-sericite zone of different veins throughout the district generally show the changes described above, some variation exists in the intensity of alteration. In the specimens of highly silicified andesite porphyry, the original phenocrysts as a rule can be identified by the rectangular patches of clear and coarse quartz. In specimens only slightly silicified, the sericite and hydromica are more abundant than the quartz.

Where the quartz-sericite alteration is superimposed on the local propylitic type, albite and calcite have been completely replaced or leached out. Generally the low-birefringent chlorite is the last mineral to be replaced and remains as isolated remnants throughout the rock where it is replaced by the sericite and hydromica. Rutile, which is associated with leucoxene, occurs most commonly in the quartz-sericite zone.

The changes that occur where the quartz-sericite alteration is superimposed on the low intensity type of regional propylitic alteration closely resemble the changes mentioned above. The most common feature is the disappearance of albite and calcite in the zone next to the vein. Specimens of the quartz-sericite alteration adjacent to veins in the high intensity zone of the regional type, show a progressive increase in sericite and quartz accompanied by the removal of epidote, albite and some chlorite.

The mineral sequence is fairly well defined in the specimens. The earlier propylitic suite of minerals is replaced by quartz and sericite. The age of the sericite with respect to the quartz is difficult to establish because the two minerals do not show cross-cutting relationships and generally appear together mutually. However, in view of the fact that silicification tends to be the end result, it is believed the quartz does replace the sericite (Fig. 32). The groundmass appears to be more readily altered by an allophane-rich and finer-grained quartz than the phenocrysts (Lovering, 1949, p. 20). Pyrite is generally the latest mineral introduced and occurs with clear quartz in minute veinlets that cut across the earlier silicified and sericitized areas. The disseminated pyrite, though very common and typical of the quartz-sericite zone, is considered to be the same age and representative of the vein mineralizing stage.

The petrographic and field evidence definitely establish the later age and the very close relationship between the quartz-sericite alteration and the ore deposits of the Topia district. Although the alteration is not very extensive in comparison to the propylitic alteration, it is always present and surrounds every vein in the district and is therefore a very direct guide to the veins.

CHEMICAL AND PHYSICAL CHANGES

Details of the Study

In order to make a quantitative study of the changes produced by the hydrothermal solutions, a series of six samples was taken normal to the Cantaranas vein along the main cross-cut on the lowest level of the San Miguel mine. The samples were obtained at various distances from the vein across the quartz-sericite and local propylitic zones and into the fresh andesite. Two samples represent a 10 centimeter band next to the vein, one on the north and the other on the south side. Three more samples were taken south of the vein at the following points, 65 centimeters, 2 meters, and 5 meters. The sixth sample was a composite of fresh andesite lava exposed at various points along the main crosscut. It serves as a standard for comparison with the altered rocks. All six of the samples are in the same flow unit of andesite lava that forms the upper part of the Santa Ana member. The main cross-cut runs parallel with the strike of the lava unit and the samples represent the same horizon of the flow.

Bulk and powder densities, and chemical analyses were made on all six samples and the corresponding thin sections were examined. All the samples were chemically analyzed by the Instituto de Geologico of Mexico. Check analyses of the 65 centimeter sample and the fresh andesite were made by the Rock Analysis Laboratory of the University

of Minnesota. A great deal of variation existed in the results of the Mexican laboratories and after a careful examination, it was decided that these data could be used only partially because of the large errors on the SiO_2, MgO, and FeO which did not check with the mineralogical composition of the rocks.

The chemical and physical changes are diagramatically represented in Figure 33. The circles at various points of the curves and the solid lines indicate places where the data are most reliable. They are based principally on the two Minnesota analyses and an average of the two Mexican analyses at the 0-10 centimeter distance. A dashed line has been added to give the general trend of alteration where the quantitative data are lacking. This portion of the curve is based on a study of the mineralogical composition, published analyses of similar alteration (Spurr, 1905, pp. 210-279 and Finlayson, 1908, pp. 637-38), and an interpretation of the Mexican analyses. Although the results of the study are not completely quantitative, the curves as a whole provide considerable information as to the nature of the hydrothermal activity.

No chemical analyses of the regional type of propylitic alteration were made. Information on the changes that took place was obtained from published analyses of propylitic alteration, the mineralogical composition of the altered rock, and a comparison with those portions of the curves from Figure 33 that represent propylitic alteration of the local type. The best evidence as to the nature

of the changes is the record of the alteration at the San Miguel vein because the low intensity zone of the regional propylitization is mineralogically similar to the local propylitic type. The chemical changes produced in the epidote-rich, high intensity zone can only be inferred from a study of the mineral composition of the altered rock.

The data on the physical changes in alteration were obtained from the bulk and powder densities determined by the writer. The analytical balance was used for the bulk density determinations and the specimens were coated with wax to prevent absorption of water. The powder densities were determined by use of a volumetric flask and the porosity was calculated from the bulk and powder densities.

Changes in the Local Propylitic and Quartz-Sericite Types

Physical Changes. The physical changes that took place in the alteration zone of the San Miguel vein are clearly demonstrated by the porosity and bulk density curves of Figure 33. The porosity steadily increased during propylitization from 3% for the fresh andesite up to a maximum of 22% at the transition point between the quartz-sericite and local propylitic zones. The porosity decreased from this maximum to 10% adjacent to the vein. This decrease is the result of sericitization and silicification of the porous zone produced by propylitization.

The record of relative porosity indicates that propylitization is essentially a leaching process in which more

is removed than introduced, whereas, the quartz-sericite alteration is essentially an additive process. More material is added than removed but not enough is added to reduce the porosity to that of the original fresh andesite. An important conclusion is that propylitization may increase the available amount of open space thereby providing a more permeable zone along the controlling fissure for the later quartz-sericite alteration and vein mineralization.

Chemical Changes. The chemical changes that have taken place in the wall rock can be correlated readily with the mineralogical changes. Some constituents have been added during the alteration and others have been removed, but the overall result is an increase in porosity and consequent reduction in the bulk density of the final product, the wall rock adjacent to the vein. The curves are presented on the chart of Figure 33 on the following page and they show diagramatically the changes as the vein is approached.

Silica is strongly leached in the propylitic zone but increases very rapidly in the quartz-sericite zone due to the abundant addition of quartz as substantiated by thin section study.

Alumina changes only slightly throughout the zone of alteration and is fairly stable in the alteration process. A little alumina is leached during propylitization but is redeposited in the quartz-sericite zone.

Ferric oxide is gradually removed from the rocks as the intensity of alteration increases. This correlates with

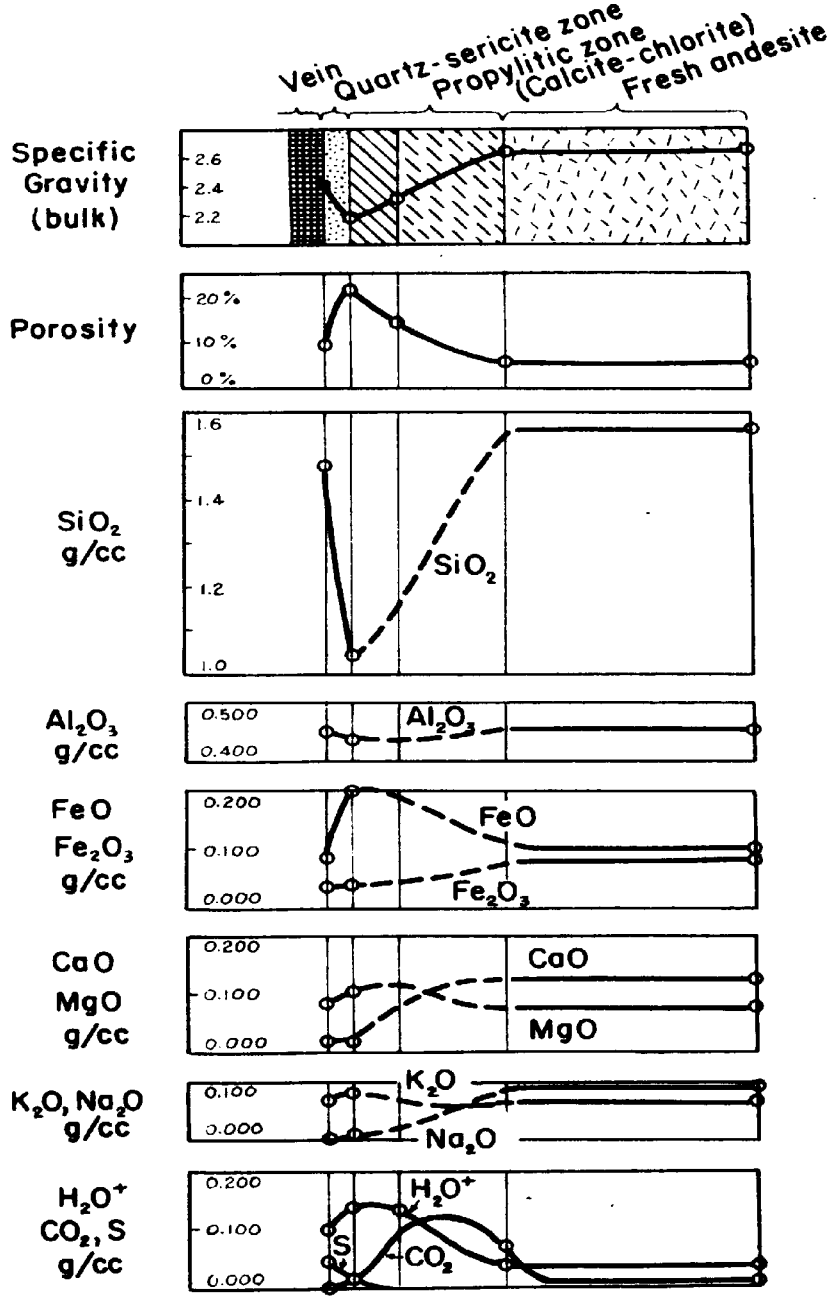


FIG.33 Chemical and physical changes adjacent to a vein

the alteration of the augite.

The ferrous oxide, magnesia, and combined water of the propylitic zone increase over the amounts originally present in the fresh rock. This reflects the abundant development of chlorite minerals during propylitization. A decrease of the ferrous iron, magnesia and water in the quartz-sericite zone corresponds to the replacement of chlorite by quartz and sericite-hydromica.

Very little change occurs in the potash of the rock. Some potash is removed by propylitization but it is added at the outer fringe of the quartz-sericite zone where sericite is most abundant. The potash of the quartz-sericite zone decreases slightly as the vein is approached because of the increasing intensity of silicification.

Both soda and lime are gradually removed during hydrothermal activity. It is interesting to note that although albite is the earliest of the propylitic minerals, no soda has been added during the early stage of alteration. Instead, the soda content drops and this agrees with the observed replacement of albite by other alteration minerals such as calcite, allophane, chlorite, sericite and quartz. The formation of albite without the introduction of additional soda may be accounted for by a rearrangement of the soda and lime present in the original andesine plagioclase. The albite probably formed as a result of the early removal of the lime from the andesine. The lime then combined with carbon dioxide to form calcite, leaving the plagioclase relatively rich in soda thereby causing

the formation of albite. In his study of albitization in a quartz monzonite at the Ajo district, Arizona, Gilluly (1946, pp. 30-31), concluded that the albitization is due more to the removal of CaO from the plagioclase than to the introduction of Na_2O. At Ajo the chemical analyses of the albitized rocks, show a slight decrease in soda and a considerable decrease in lime.

The abundant calcite in the propylitic zone is confirmed by the presence of carbon dioxide in the rock analyses. The carbon dioxide decreases rapidly as the vein is approached and this is in accordance with the petrographic study which shows that all the calcite is removed in the quartz-sericite zone.

The increase in the sulfur content as the vein is approached indicates that pyrite is more abundant near the vein. It appears to support the petrographic evidence that shows some of the pyrite is very late in age.

In summary, the propylitic zone shows an increase in ferrous iron, magnesia, carbon dioxide and combined water and a marked decrease in all other constituents, especially silica. On the other hand, the quartz-sericite zone is characterized by the abundant introduction of silica, the slight addition of potash, alumina and sulfur, and the removal of the remaining constituents; ferric iron, ferrous iron, magnesia, lime, soda, water, and carbon dioxide.

Changes in the Regional Propylitic Type

No chemical analyses of the regionally altered propylitic rocks were made; nevertheless, some variation of the several zones is indicated by the progressive increase in epidote and in calcite as the intensity of the alteration increases.

The low intensity zone of the regional type is mineralogically identical to the local type and the two are probably similar in chemical composition. The presence of abundant calcite indicates that the principal chemical change has been the addition of CO_2. The alumina and potash were fairly constant; the behavior of lime would depend on the relative abundance of calcite in the altered rocks. The common occurrence of chlorite probably denotes that a small amount of magnesia and water have been added as well as some ferrous iron. However the iron content may be fairly constant as the ferrous iron could form at the expense of the ferric iron. Silica and soda were probably removed to some extent. Several published analyses of calcite-bearing propylitized andesites tend to confirm the changes mentioned. The table below gives the comparative analyses of fresh and propylitized andesite from Tonopah, Nevada and the Thames district, New Zealand.

TABLE II

A COMPARISON OF FRESH AND PROPYLITIZED ANDESITES

	Tonopah, Nevada*		Thames, New Zealand**	
	1	2	3	4
SiO_2	62.16	55.60	57.42	52.69
Al_2O_3	16.45	16.70	17.61	18.33
Fe_2O_3	3.27	2.23	2.34	2.32
FeO	2.71	3.51	3.77	2.98
MgO	2.20	2.60	2.19	3.09
CaO	4.13	4.27	5.69	7.87
Na_2O	4.07	4.08	3.22	2.62
K_2O	3.45	3.17	1.94	0.98
H_2O	1.15	3.94	3.47	4.44
CO_2	----	2.76	0.95	3.59
TiO2	----	----	0.68	0.53

1. Average type mica-hornblende andesite, Tonopah, Nevada.
2. Early andesite, chloritized; Siebert Shaft, Tonopah, Nevada. G. Stieger, analyst.
3. Fresh hornblende andesite, Thames district, New Zealand.
4. Chloritized hornblende andesite, Halycon Mine, Thames district, New Zealand.

* Spurr, J. E., (1905) U.S.G.S. Prof. Paper 42, p. 219.

** Finlayson, A. M., (1909), Econ. Geol., vol. 4, p. 637.

The degree of change in the composition of the rocks on passing from the intermediate to the high intensity zones is more difficult to establish, but it is evident that the greatest change would be a decrease in the carbon dioxide content because of the diminishing amount of calcite. The lime that remains tends to react with silica to form epidote [$Ca_2(Al,Fe)_2(AlOH)(SiO_4)_3$] in place of the calcium carbonate. The silica may be provided from the rock or it

may be introduced. Ferrous iron and magnesia would either increase, decrease, or remain fairly constant depending on the abundance and the composition of the chlorite present.

CHAPTER IV

ORE DEPOSITS

GENERAL STATEMENT

The ore deposits of the Topia mining district consist of a series of parallel northeast veins which have been exploited for their silver content and minor amounts of lead and zinc. The total production of the district is not accurately known because of the lack of records, but it is estimated that ore valued at from 10 to 20 million dollars has been produced by small scale mining methods.

The ore deposits, restricted to the andesites, occur throughout the district in a series of long narrow veins which have a strike averaging N.60°E. and dip to the south at about 80°. The productive veins, located on the north side of the canyon near the town of Topia, occupy northeast fault fissures which have a strong horizontal component of movement. The fissures are considered to be shears which formed in early Tertiary time as a result of regional tectonic forces.

The mineralization of the veins consists essentially of simple sulphides and sulphosalts of lead, zinc, and silver in a predominantly quartz-rich gangue. An extensive propylitic alteration and a narrow zone of quartz-sericite

alteration are related to the mineralization of the veins. The hydrothermally altered breccia zones along the fissures have been filled and replaced by the vein minerals. The veins are ore-bearing over long distances along their strike; base-metal sulphides are found throughout a composite vertical distance of over 1000 meters.

Some evidence of horizontal zoning in the veins is present and is expressed in the decrease of copper and gold in the ore as well as a decrease in the iron content of the sphalerite toward the northeast. The vein mineralization and hydrothermal alteration are believed to be related to the granodiorite stock that occurs in the southwest part of the district.

DESCRIPTION OF THE VEINS

Distribution

Nine main veins and over 40 minor veins were mapped in the andesites of the district. The detailed distribution and their relationship to local structure are presented on Plate III. Most of them are concentrated north of Rio Topia and near the village of Topia. Because of the abundant Tertiary-Quaternary gravels and other types of cover, the veins do not form a continuous broad outcrop. This is especially true south of Rio Topia where the extensive cover undoubtedly obliterates a large number of veins. An unknown number of unmapped veins are also present in the

western part of a district near the granodiorite stock. The veins on the whole are continuous structural features and many of them extend beneath the rhyolites.

Because of the discontinuous outcrops, various segments of the main veins have been given different names. In order to standardize the terminology, each vein is named after the largest mine or claim with which it is associated. The five veins north of the river have been or are at present the principal producing veins. Four veins south of the river are considered to be main veins because of their limited production in the past and future possibilities. The principal veins from north to south are as follows:

1. Argentina vein -- This vein is seen on the surface for about 700 meters along strike due north of Topia very close to the rhyolite contact. It has an attitude of N.60°E., 60°S. The Argentina, which is one of the oldest producers in the district, is the most important mine on the vein.

2. Cantaranas vein -- The vein outcrops in two places only; for a distance of 800 meters two kilometers northeast of Topia and for a distance of 500 meters due west of Topia. It strikes N.55°E. and dips 80°S. The San Miguel is the principal producing property on the vein. The old workings of the Cantaranas mine make it possible to trace the vein beneath the gravel cover.

3. La Perla vein -- The La Perla vein, from which more ore has been produced than any other in the district, is the largest and best exposed vein in the district and

can be traced for about four kilometers on the surface except for the covered portion where it passes underneath Topia. Its overall attitide is N.70°E., 80°S. The important mines on the vein are the Tres Varones, Cocinera, La Perla, and El Salto. Because of excellent outcrops in the accessible part of the area, the La Perla is believed to be the discovery vein of the district.

4. La Dura vein -- The vein is poorly exposed and outcrops only on Los Hornos ridge just west of Topia. The La Dura workings are located on the vein which has an attitude of N.64°E., 80°S.

5. Las Animas vein -- This is the last important vein north of Rio Topia and is the second most prominent vein in the district. The vein has a strike of N.55°E. to N.62°E. and dips from 75° to 80°S. The Colorado and San Felipe mines are located on the vein in the western part of the district; the Las Animas, Santa Rosa, and Olivia mines have produced ore from the vein in the central part of the district.

6. San Gregorio vein -- The San Gregorio and San Nicolas workings are located on a vein that extends for about one kilometer southeast of Topia on the south side of the canyon. The vein has a strike of N.60°E. and dips 80°S. to vertical.

7. Amarilla vein -- Because of the cover, only a few meters of this vein are exposed on the south side of the canyon about 600 meters north of Mt. La Ojeda. Some ore has been produced from the Amarilla workings. It

strikes N.60°E.

8. La Prieta vein -- Some ore has been produced from the vein at the La Prieta mine, which is located in the canyon of Rio Escalera about 700 meters south of Mt. La Ojeda. At the mine the vein strikes N.50°E. and dips from vertical to 80°N.

9. Navidad Madrid vein -- This is the southernmost vein in the district and is exposed for several meters in the bottom of Escalera canyon. Several small prospects which look promising are located on the vein which has an attitude of N.48°E., 70S.

Structural Details of the Veins

Attitude of the Veins. Because all of the veins have the same general strike, they form a distinctive parallel pattern throughout the district. The strike of the main veins varies from N.55°E. to N.70°E. and the average trend of most is N.60°E. As a rule the veins dip south at an average of 80°, but in some the dips range from 45°S. to vertical. One vein dips 80°N. No northwest veins have been found except for local mineralization along the Ojeda and Hornos faults of the northwest system. (See General Geology.) Although minor branching is common on most of the veins, none are connected by the branches.

Pre-Mineral Faults and Fissures. The primary structural control for the veins is the N.60°E. fault system of parallel shears formed during the early Tertiary history of the district (Local structure, General Geology).

Subsequent selective mineralization of the breccia caused by the shearing formed the veins.

The original amount of displacement along the pre-mineral faults is obscured by post-mineral movement parallel with the veins (N.60°E. fissures and faults, General Geology). The later movement is considered to be less than the original displacement (Post-mineral faults, Ore Deposits). Enough information is available along the La Perla vein to give a good estimate of the pre-mineral movements. The solution is based on the Santa Ana tuff-lava contact which is displaced horizontally 118 meters by the vein on Tepalcates ridge (Fig. 34) and on the 46 meter horizontal offset of the quartz latite dike on Los Hornos ridge. The contact strikes N.10°W. and dips 10°W.; the dike, N.30°W. and 70°E. A very strong horizontal component of movement is indicated in which the south side of the vein moved to the east and down. The net slip was found to be 53 meters with a strike-slip component of 51 meters and a dip-slip component of 19 meters. The net-slip plunges at the low angle of 19° and forms a pitch angle of 14°. The displacement can be classified as right-hand movement in which the right-hand wall, when sighting along the strike of the vein, has moved forward.

Not enough data are available along other veins in the district to compute the displacement so that it could be compared with that of the La Perla. However, on six veins where contacts have been offset, the displacement of the contact is such that it can most readily be explained

by the south side likewise moving down and to the east in an apparent right-hand relationship. The offset on the other veins does not appear to be as great as on the La Perla.

On several veins, branching veinlets form an angular horsetail type pattern similar to that observed along the La Perla vein. In all cases the branching reflects a pre-mineral right-hand movement along the veins (Minor branching veins, Ore Deposits).

In view of the overall relationships such as the strong horizontal movement and branching on the La Perla vein and similar apparent displacement and branching characteristic of the other veins, the vein fissures are considered to be shears. Because of their parallelism with other northeast faults, it is believed that they represent the main shearing direction in the district. It is possible that the early northwest faults formed a complementary set of shears with the northeast faults (McKinstry, 1948, p. 353). However the greater amount of normal type displacement and the earlier age of the northwest faults appear to indicate that they comprise a separate set (Origin of the faulting, General Geology).

The selective mineralization of the northeast fissures indicates that they were better channelways for the solutions than the northwest faults. The brecciation formed by the faulting probably provided more open space for the subsequent mineralization. However the preferential orientation of the fissures may be a possible explanation

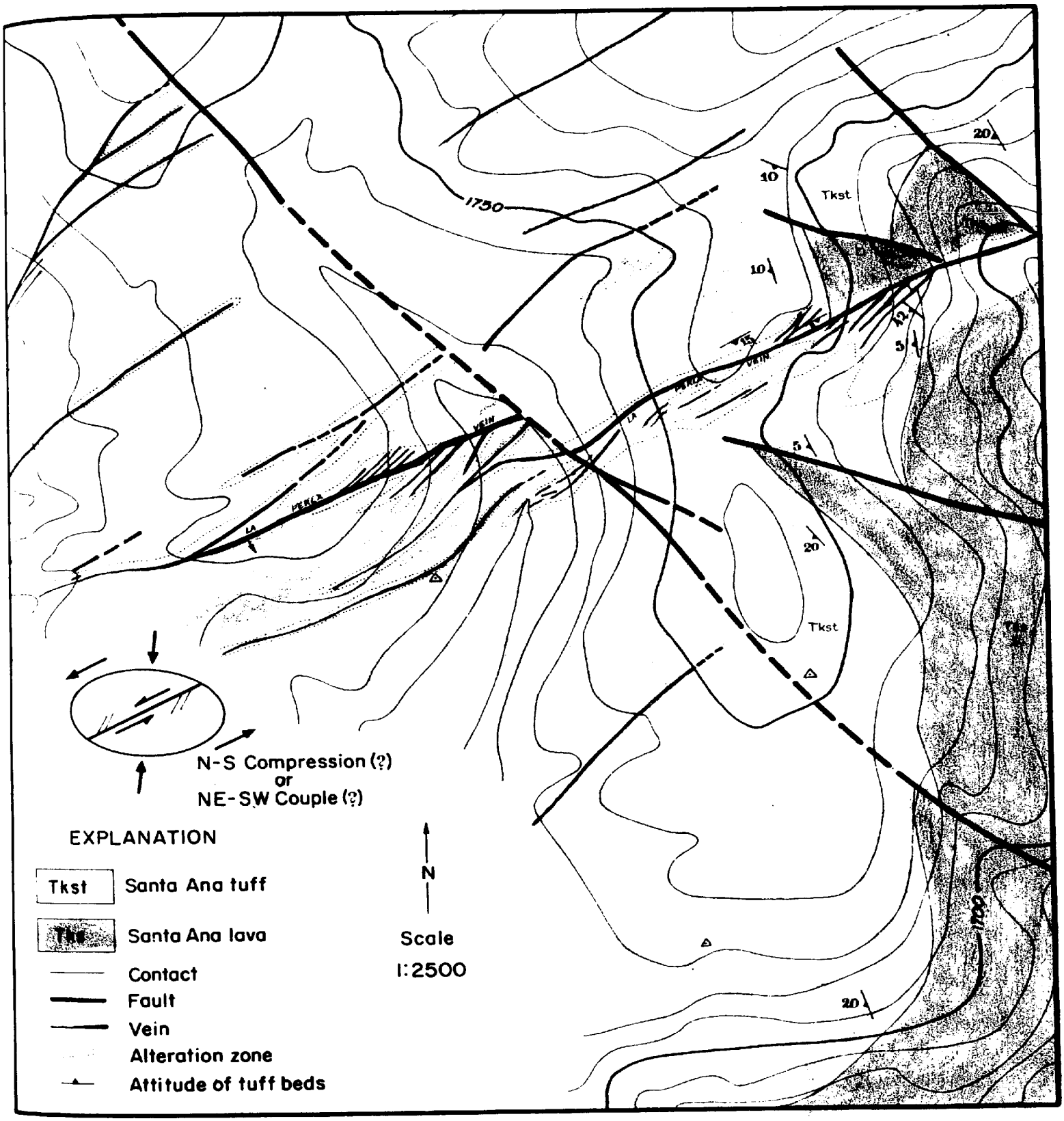


FIG. 34 Geologic map of the La Perla vein on Tepalcates Ridge showing the surface details of the La Perla vein, alteration zone, and orientation of forces.

for the selective mineralization. Fissures of northeast strike provided favorable channelways extending out from the granodiorite stock which is believed to be the center of hydrothermal activity.

Minor Branching Veins. Numerous branching veins or stringers give a local horsetail character to many veins although in all cases the main vein is a continuous through-going structure. Figure 34, which is a detailed surface map of the La Perla vein on Tepalcates ridge, demonstrates the branching nature of the veins. The stringers leave the main vein at a small acute angle swinging to a more northerly strike and disappearing into the walls in a pattern which is characteristic of tensional breaks associated with shearing. The stress diagram for the relationship of the branching veins to the shearing direction is shown on Figure 34.

On the veins where branching structure has been observed on the surface, the angular relationship of the stringers and the main vein indicates that the north side moved west and the south side east. Tensional fractures and feather joints commonly associated with shear zones generally tend to swing toward the axis of compression but rarely make a 45° angle with the shearing (McKinstry, 1948, pp. 298-99). Similar patterns related to shear have been observed in many other districts such as Chuquicamata, Chile (Lopez, 1942, p. 126); Real del Monte, Pachuca, Mexico (Wisser, 1942, pp. 233-239); and the Perron Mine,

Quebec (Ames, 1948 p. 897).

The stringers are very narrow and are generally less than one centimeter wide; a few may be as much as 2 to 5 centimeters wide. As a rule a texture indicative of open filling is characteristic of the minor branching veins, and the mineralization consists mostly of comb quartz with a small amount of pyrite and base-metal sulphides.

Cymoid Structure. In two places within the Tres Varones mine and the San Felipe workings of the Colorado mine, a branching of the main vein forms a cymoid loop associated with a change in direction of the vein (McKinstry, 1948, pp. 315-18). Figures 35 and 36 show the two cymoid structures in plan view.

The additional opening caused by the vein swinging to the left toward the direction of tensional fracturing is typical of right-hand movement. In each case the elements of the loop, which range in width from 10 to 20 centimeters, are thinner than the main vein but are nevertheless well mineralized with base-metal sulphides. Although the dip of the veins is fairly regular for the most part, several changes in dip have been noticed in some of the mines, generally where the vein changes direction. Cymoid structure in a vertical section is believed to be associated with local changes in dip but it was not observed because of the lack of available mine openings.

Post-Mineral Faults. A considerable amount of cross faulting and faulting along the veins can be seen in

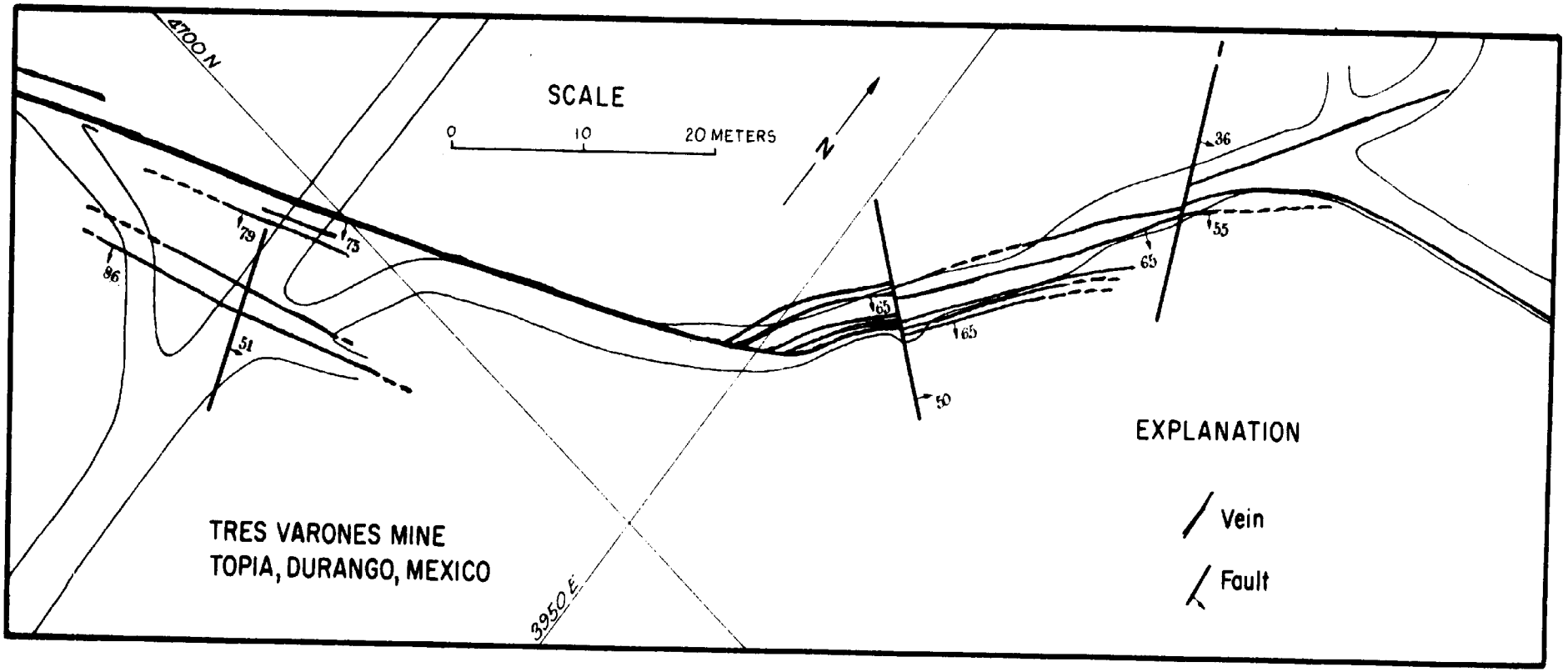


FIG. 35 Plan showing the branching of the Perla vein with the change in strike to form a cymoid loop.

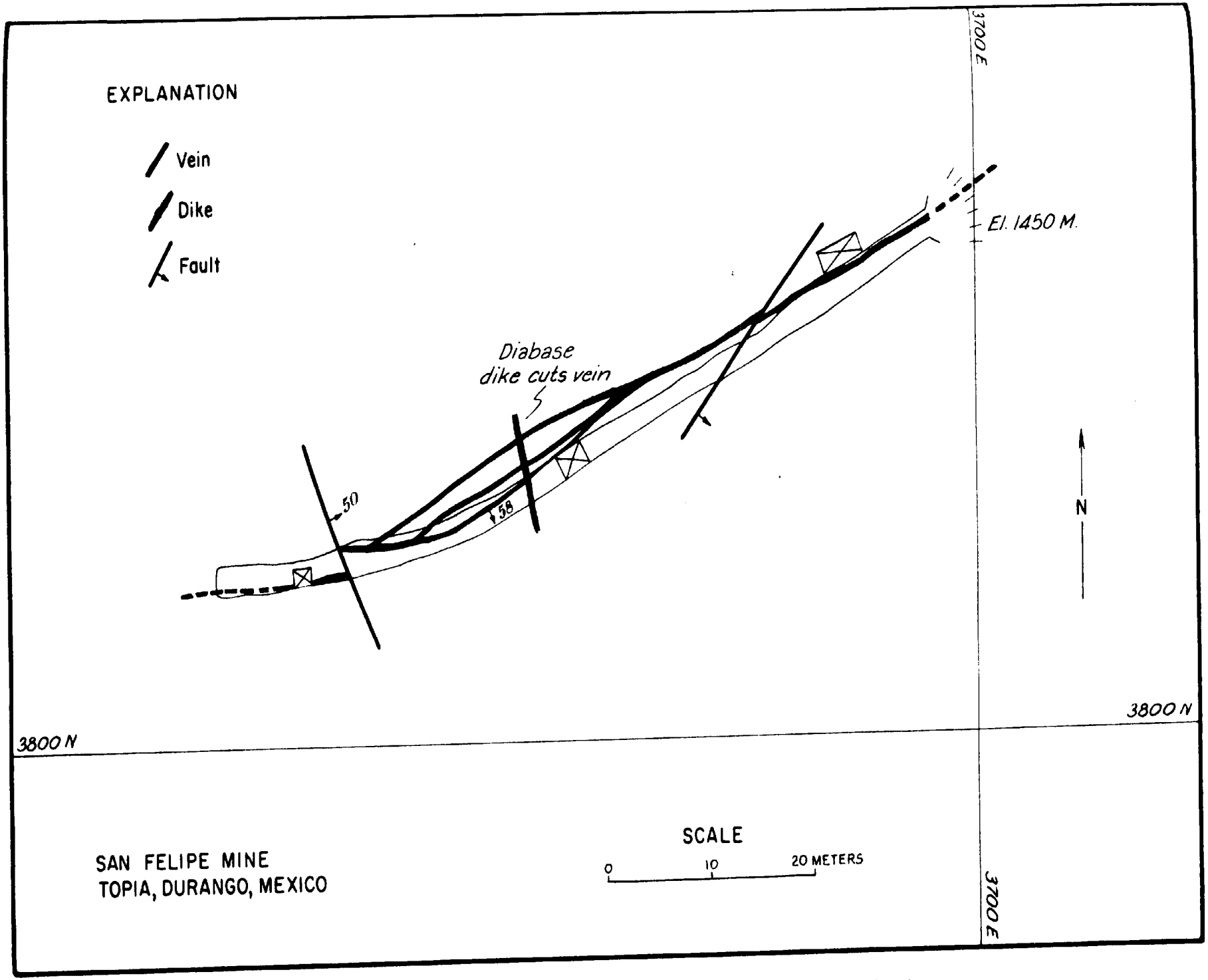


FIG. 36 Plan showing the branching of the Animas vein coinciding with the change in strike to form a cymoid loop.

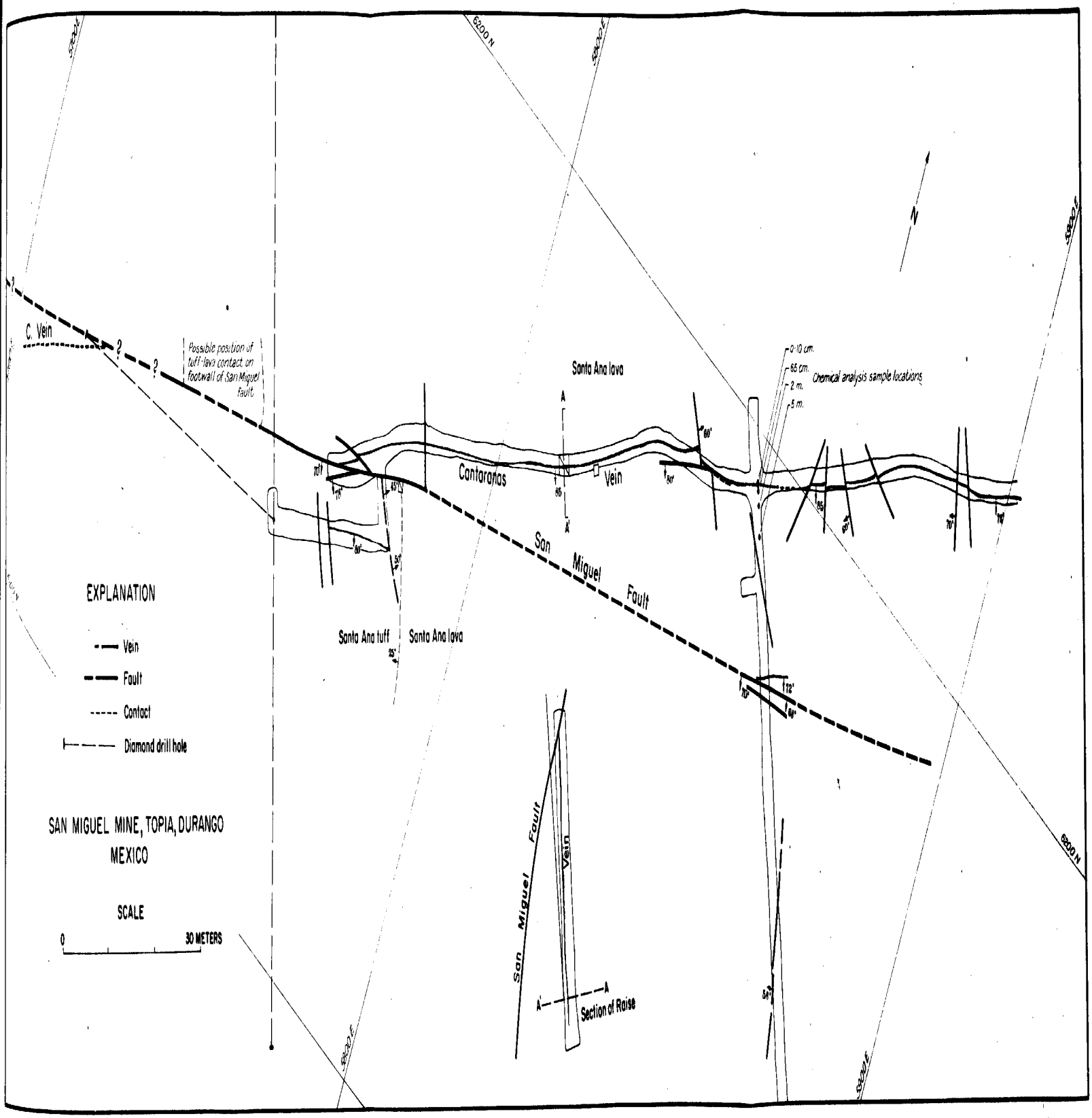


FIG. 37 Plan of the San Miguel Mine showing several post-mineral faults.

all the mines. Figure 37, which is a plan view of the San Miguel mine, demonstrates several minor northwest cross faults and a fault parallel with the vein. The faults that offset the vein generally have a very small displacement and to date none of the major northwest faults, except the Victoria fault, have been found in the underground workings.

The majority of the cross faults have a northwest strike that ranges from N.30°W. to N.50°W. and an easterly dip of 60° to 80°. The faults offset the veins a meter or less and in most places the vein is displaced to the south on the east side of the fault. In some places the vein is not offset by the northwest faults; this may indicate nearly vertical movement along the post-mineral faults. Although a pre-mineral age for such faults may be possible, no mineralization spreads along the cross fault. Some cross faults which strike from N.10°E. to N.20°E. and dip to the east at a high angle have been observed underground. These northeast faults offset the vein generally less than a meter. However in the Tres Varones mine, the La Perla vein is displaced by the northeast faults as much as three meters to the south on the east side of the fault. Not enough information is available in the underground workings to determine the type of movement that has occurred along the northwest or northeast cross faults, but, in view of the relatively small amount of horizontal displacement, it is believed that the normal type movement has taken place. This is similar to that on the larger faults (Northeast

faults, General Geology).

Faults striking parallel with the vein are especially prominent in the Tres Varones mine, where post-mineral movement has gouged and brecciated the ore in many places. The faults generally follow the vein for a considerable distance, gradually crossing from one side of the vein to the other. In places branches of the fault curve away from the vein and enter the walls. The fault surface may form a "false" wall along the side of the main drift. The presence of abundant nearly horizontal striations indicates that the late movement had a strong horizontal component. Further indication as to the displacement along the parallel faults is found in the San Miguel mine (Fig. 37) where a post-mineral northwest cross fault has been offset by faulting along the vein. The faulting paralleling the vein has shifted the northwest cross fault 2 1/2 meters horizontally in a manner similar to the right-hand type of displacement of the pre-mineral northeast faults. The presence of post-mineral faulting along the veins indicates adjustment along earlier lines of weakness (Origin of the faulting, General Geology).

Vein Texture

The most striking textural feature of the veins is the banded character of nearly all the ore. Figure 38 illustrates typical banding shown by the Cantaranas vein of the San Miguel mine. The banding is parallel and consists

of dark-colored layers rich in base-metal sulphides, pyrite, and quartz, alternating with bands of white comb quartz. As many as five distinct bands have been observed but generally only three main bands are present. The structure generally consists of two dark-colored bands separated by a central band of white comb quartz or the reverse. The thickness of the main bands ranges as a rule from 3 to 10 centimeters. The galena and sphalerite of the banded ore vary from coarse to medium-grained, but the quartz, especially the crystals in the comb structure, is finer-grained, the units ranging from 2 to 5 millimeters across.

Three general types of bands generally are present in the veins. The most common type is a dark-colored band in which abundant galena, sphalerite, and some quartz are present. The second type is composed of a dense aggregate of darker gray quartz and pyrite. The third type is similar to the first but is light-colored and contains an abundance of white comb quartz which grows outward from the walls. The vuggy interior of the band is filled with patches of galena, sphalerite, pyrite, barite, or calcite.

A fourth type of banding is represented by the "spotted" or "raisin" ore (Fig. 39). It is very common in the San Miguel mine and in many respects is a variation of the third type described above. The band averages from 3 to 10 centimeters in width and has a moderately fine texture. It consists mostly of an interlocking aggregate of light gray quartz crystals averaging 2 millimeters in length among which are distinctive hexagonal areas of black

Figure 38--Specimens of the Cantaranas vein from the San Miguel mine showing the typical banding seen in many of the veins.

Figure 39--"Raisin" or "Spotted" texture seen in specimen from the San Miguel mine. The hexagonal-shaped cross-sections of sphalerite crystals cause the spotted appearance. (Full size)

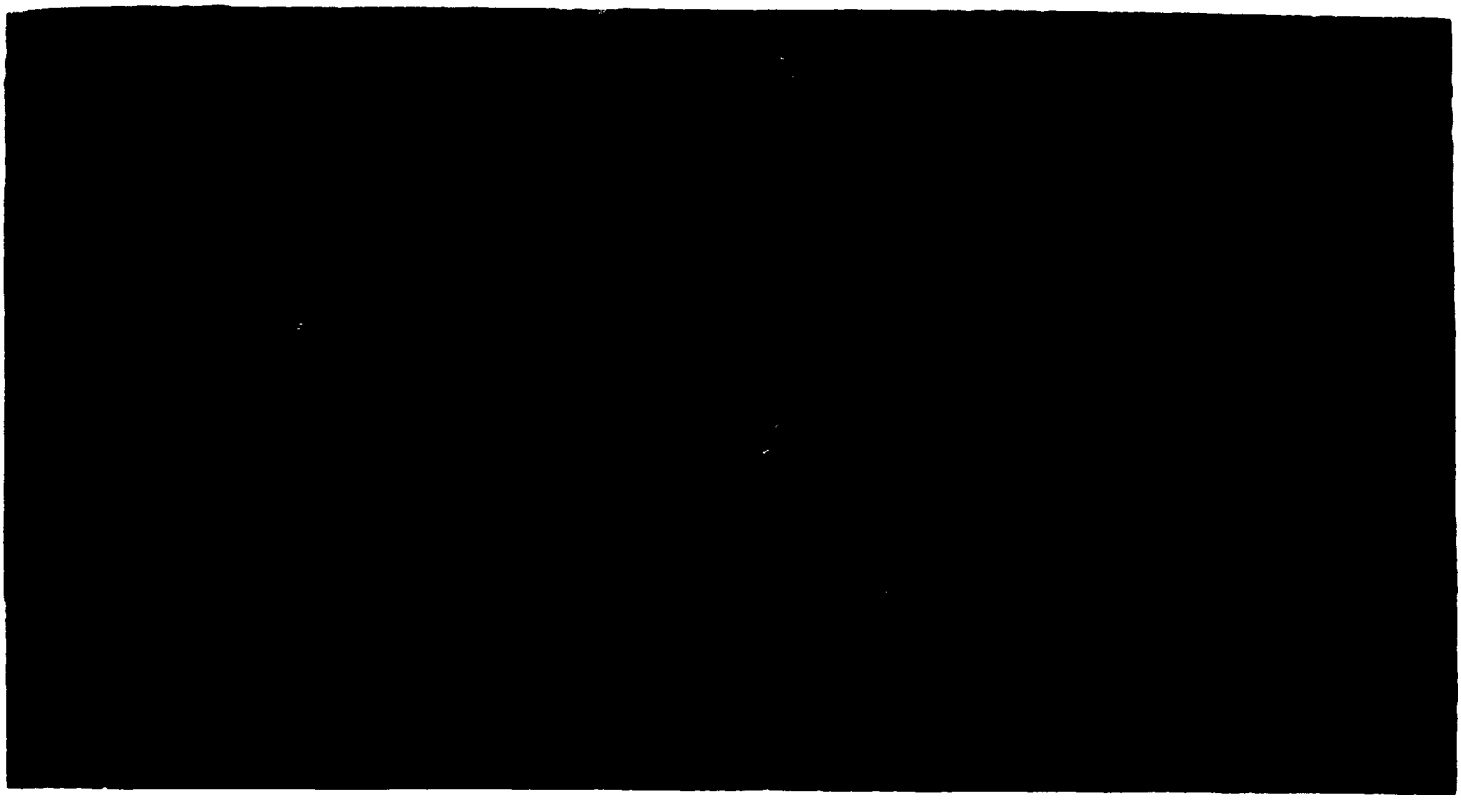


Fig. 38



Fig. 39

sphalerite. The sphalerite areas are individual crystals averaging 10 millimeters in diameter. Small grains of galena or ruby silver minerals occur interstitially in the quartz. Vugs are common in the "spotted" ore.

The small branching veins or stringers have a structure very similar to the third type described above. The entire stringer is essentially one band with an outer margin of comb quartz and a central vuggy core of galena or sphalerite. On close inspection thin seams of comb quartz 2 to 5 millimeters wide can also be distinguished within the veins or nearby wall rock. These may be parallel with the main bands or they may transect them.

The vugs, comb structure, coarse crystalline character of the galena and sphalerite, and the common occurrence of euhedral sphalerite indicate that much of the ore was deposited in open fractures. The "spotted" texture is also an excellent example of filling.

Replacement textures, observed in many places, are best shown in the Las Animas vein at the Olivia mine. Here the vein is about one meter wide and is composed mostly of a dark-colored, fine-grained, silicified breccia with minute grains of galena, sphalerite, and pyrite disseminated throughout the mass. Figures 40 and 41 show several replacement specimens of silicified breccia from the Olivia and other mines in the district. Small quartz-lined cavities commonly border the rock fragments. As a rule the replacement quartz has a darker color than the crustified quartz, and pyrite is commonly associated with it. In other veins

Figure 40--Specimen on the left is silicified breccia from the Trinidada vein with vuggy openings at the border of fragments. The specimen on the right is part of the La Perla vein from the Tres Varones mine showing the typical white open filling type quartz surrounding areas of darker gray replacement quartz representing silicified fragments.

Figure 41--Several specimens of silicified and mineralized breccia from the Las Animas vein at the Olivia mine.



Fig. 40

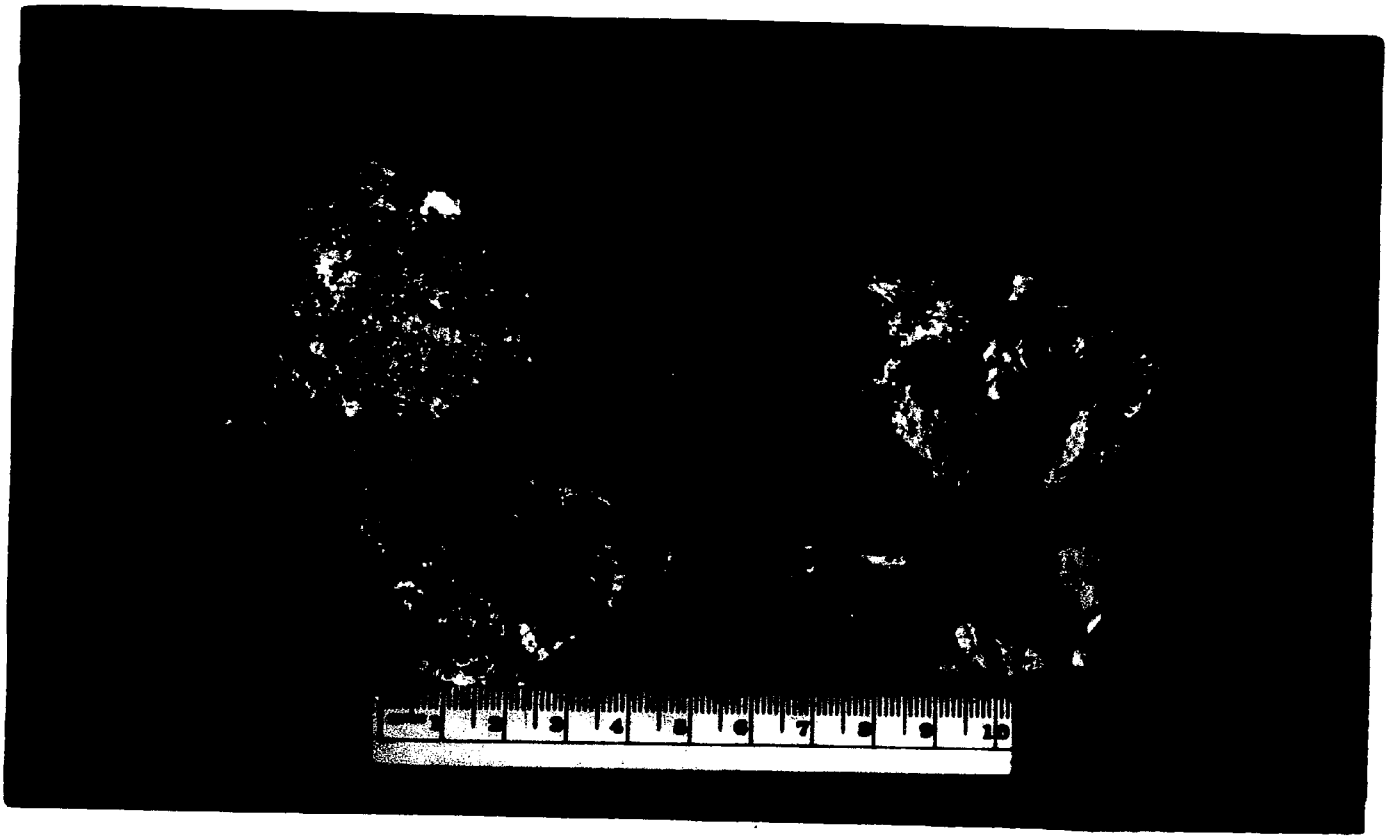


Fig. 41

where the banding is prominent, the pyrite-rich, dark gray quartz bands are believed to represent replacement of the wall rock. Silicification and deposition of pyrite are commonly associated with replacement textures whereas the deposition of the ore minerals is favored by open filling.

The banded ores at Topia are considered to be the result of reopening of the vein fractures, perhaps due to small scale shifting of the walls. The bands are generally parallel but some seem to pinch out or swell and comb quartz veinlets commonly transect the older bands.

Ore Shoots

The distribution and size of the ore shoots are not known because of the lack of old records as to vein width, grade of ore and production, and also because of the insufficient amount of work completed in recent mining operations. An examination of the veins underground and on the surface indicates that the degree of sulphide mineralization and width of vein vary along strike. Old mine maps of the main veins north of Rio Topia show that, although the stopes extend horizontally for considerable distances and suggest an elongate shape for the ore shoots, there are limitations in the mineable portions of the veins. Most of the veins mapped are too narrow to be mined and even though ore minerals are present in all of them, relatively few are ore-bearing. In some places the veins consist mostly of quartz and in other places the base-metal sulphides are

very abundant. Since silver is commonly associated with galena and sphalerite, the base-metal content gives a good indication of the grade. Three main factors may be related to the distribution and size of the ore shoots: (1) structural details of the vein, (2) variation in wall rock, and (3) changes in mineralization with depth.

Structural Controls. Base-metal sulphides are relatively more abundant where the vein is wider, and the factors controlling the formation of open space have therefore had a strong effect on the distribution of the ore shoots. The local variation in the width of the veins is believed to be related in some places to a change in the attitude, and in others to the abundance of brecciation. Fault-vein intersections, which exert a favorable local control on ore deposition in many districts, appear to have had no effect in the Topia district.

In the two cymoid structures of the Tres Varones mine and the San Felipe workings, the individual branches are narrower than the main vein but their composite thickness is much greater (Figs. 35, 36). In both places the individual elements of the loop are well mineralized with galena and sphalerite. It is believed that additional open space provided by the cymoid structure materially aided deposition of ore in the immediate area.

In the Tres Varones mine one of the minor veins, which lies parallel with and north of the La Perla vein, widens to one meter of pure galena and sphalerite where

the vein swings to the left and the dip flattens from 80°S. to about 40°S. The vein thins out and steepens in directions away from the bend. A large amount of brecciation is present at the bend and evidently the additional open space available as a result of the brecciation caused a local thickening of the vein. The effect of the unusually flat dip, which is believed to be a local variation, cannot be evaluated at present.

Wall Rock Control. The veins at Topia occur in two types of andesite which are chemically homogenous but differ considerably in their physical character. The andesite lava is a tough brittle rock of low porosity which brecciates readily, whereas the andesite tuff is a softer porous rock which is less competent and does not brecciate as well. In their structural behavior, the tuffs, especially where fine-grained, resemble siltstones and mudstones. Gouge and slips along bedding planes are common. Nevertheless the pre-mineral fissuring and subsequent mineralization show no marked contrast in the two rock types.

In order to see if the wall rocks exerted any influence on the deposition of ore, longitudinal sections of the old mine workings have been prepared (Fig. 42). It is evident that ore occurs in both types of rock, but more ore has probably come from veins in the lavas than from those in the tuffs. This is true because of the extensive stoping in the El Salto mine along the La Perla vein which occurs in the Santa Ana lavas. Nevertheless some ore shoots occur

in the tuffs and there is no conclusive evidence that one rock type is more favorable than the other. However the veins in the lava commonly show much less minor branching than those in the tuffs. More brecciation along the veins is also characteristic of the lavas. Since the lavas brecciate more readily, it would be expected that more open space would be available and that the lavas would therefore be the favored rock type. The fact that neither rock is favored to any degree may be due to the greater initial porosity of the tuffs, which would tend to balance the higher degree of brecciation in the lavas.

Changes with Depth. Because of the unusual relief in the district, veins with typical quartz, galena, sphalerite, and pyrite are exposed at elevations ranging from 950 meters in the canyon of Rio Topia to 2040 meters at the Manzanilla vein in the northern part of the district. Thus the vertical extent of known mineralization exceeds 1000 meters. The best information on the mineralization comes from the restricted zone of active mining which is within the interval from 1500 to 1750 meters on the north side of the canyon. Only scattered veins and prospects were observed at the surface above and below this zone. Because of the lack assays, a special attempt was made to obtain specimens for polished section study, especially from elevations below the zone of active mining. Observations over the entire range of 1000 meters showed the presence of the sulphides of iron, lead, zinc, and copper in a quartz gangue,

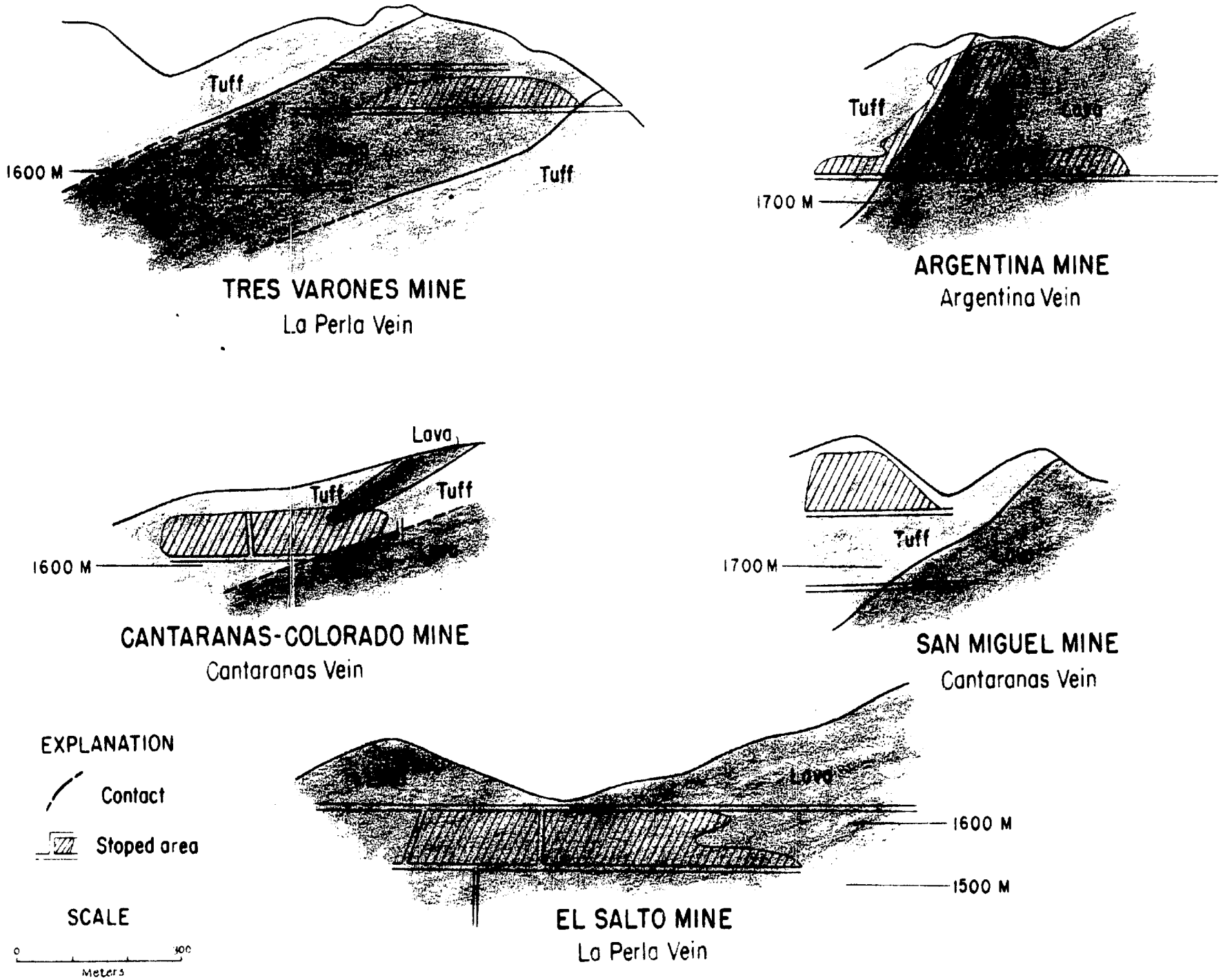


FIG. 42 Longitudinal sections of old mine workings showing the relationship of ore shoots and wall rock.

although the exact proportion of ore minerals is not known.

Some changes in the character of vein texture and mineralization have been noted at depth. Veins exposed in the canyon at an elevation of 1200 meters or less are poorly mineralized with sulphides but very rich in quartz. These deeper veins do not appear to be ore-bearing. The quartz and pyrite have a coarser texture than they do in the main part of the district at higher elevations. Polished sections were prepared from a quartz vein, 30 centimeters wide, exposed in the bed of a creek due south of the Tres Varones mine in the vicinity of the quartz monzonite plug at an elevation of 1205 meters. The sections show abundant pyrite and arsenopytite, as well as some galena, sphalerite, and freibergite. There is more chalcopyrite than in typical specimens from the main part of the district. A vein outcropping in the bottom of Topia Canyon at an elevation of 950 meters in the western part of the district had a very coarse texture and abundant coarse pyrite as well as abundant green copper stains. Only a little galena and copper were present. The impression gained from field observation and polished section study is that although the mineralogical bottom of the veins has not yet been reached, coarser textures, more copper, and less lead, zinc, and silver can be expected with depth. However, since the deeper veins are exposed west of the main part of the district, it is not known whether the variations noted reflect actual changes with depth, a horizontal zoning towards the west or possibly a combination of both (Mineral zoning,

Ore Deposits).

The mineable shoots as determined by their combined lead, zinc and silver content, probably do not have a great vertical range. At present the majority of the mine openings and prospects in the central part of the district are at elevations of 1450 to 1750 meters. In the southern part of the district south of Rio Topia, the old mines and prospects range in elevation from 1350 to 1500 meters. Nearly all the workings fall within elevations of 1300-1750 meters. In view of the lower elevation of the old workings on the south side of the canyon, it is possible that the main zone of lead and zinc mineralization may be inclined to the south. The present workings may represent a fortuitous control by the topography in that the 1300-1750 meter range is the most accessible part of the district. The problem of variation with depth cannot be answered until more data from assays, mine openings and exploration are available.

The upper limit of the ore horizon is not known because most veins above the 1750 meter elevation were removed by extensive erosion in the canyons. However in the extreme northeast corner of the andesite window (Plate III), a good showing of galena and sphalerite in a quartz-barite-calcite gangue was observed in the prospects on the Manzanilla vein (2040 meters). Although it is difficult to judge on the basis of a single vein, there is a possibility that the main ore horizon once extended above 1750 meters.

Structural History and Age of the Veins

The parallel veins formed in early Tertiary time along the northeast fissures which represented the main shearing direction. The fissures and a set of northwest faults, which are probably of earlier age, are the result of regional tectonic activity (Origin of the faulting, General Geology). The presence of northeast veins at Valle de Topia, 14 kilometers northeast of Topia, in alignment with the local vein system indicates the regional nature of the early stresses. Northeast-trending veins have also been reported in other nearby mining districts, such as at Sianori, 22 kilometers west-northwest of Topia, and at Birimoa, 14 kilometers to the south.

It is clear that the vein mineralization was post-andesite and pre-rhyolite. Rhyolites can be seen resting unconformably on the Argentina vein northeast of the Argentina mine. However, the exact position of the mineralization within the post-andesite and pre-rhyolite interval cannot be precisely established. It is believed that the first event was a period of faulting after which the granodiorite, quartz monzonite, and quartz latite dikes were intruded. Hydrothermal activity caused a widespread propylitization of the andesites and culminated in the mineralization of the veins. In view of the fact that post-mineral dikes were intruded along the early faults and a considerable period of erosion occurred prior to the deposition of the Miocene(?) rhyolites, it is believed the veins are of pre-Miocene age

and most likely are Oligocene or older (Regional geology, General Geology). Some faults that offset the veins also displace the rhyolite.

VEIN MINERALOGY

The vein minerals which are found at Topia are of rather common occurrence. In order to study the vein mineralogy, specimens were gathered from mines, mine dumps, drill cores, and vein outcrops from various parts of the district. A special attempt was also made to obtain specimens over a wide vertical range in order to study the possible changes in mineralization with depth. Over 50 polished sections of the ores were studied in the laboratory.

Vein Minerals

The primary metallic vein minerals recognized are: arsenopyrite, pyrite, galena, sphalerite, freibergite (argentian tetrahedrite) chalcopyrite, and ruby silver minerals. Galena, sphalerite and freibergite are the chief ore minerals. No free gold was seen in the specimens from the main part of the district although a very small amount does occur in the ore. Native silver was discovered in 1954 but no knowledge of its occurrence or relationship to the other minerals is available. Very little supergene activity has taken place but chalcocite and covellite have been found in partially oxidized specimens from mine dumps.

The primary gangue minerals are quartz, barite, and calcite. The quartz comprises over 90% of the gangue, whereas barite and calcite are only locally present as a vein filling. The most abundant supergene mineral in the old mine workings is gypsum, and in a few places some blue-green secondary copper minerals were seen.

Arsenopyrite. Arsenopyrite occurs in all the veins but is generally more abundant in the western part of the district. It is easily recognized by its steel gray color and strong needle-like or diamond-shaped crystals which average as much as 5 millimeters in length. Under the microscope the arsenopyrite is very distinctive because many of the euhedral crystals resist replacement by later minerals.

Pyrite. Although pyrite is present in all the veins and in nearly all the specimens, it is rarely abundant and is exceeded in amount by the lead and zinc sulphides. The pyrite is generally cubic or some modification of the cube. In the main part of the district it is fine to medium-grained whereas in the western part of the district and at depths below 1200 meters it is much coarser. Crystals over 5 millimeters in diameter have been noted. Under the microscope some of the pyrite occurs as euhedral crystals, but generally it forms irregular corroded masses. As a rule the later silver minerals are not closely associated with the pyrite.

Galena. Galena, a common vein mineral, occurs in large masses with a texture from medium to coarse. It has a fine-grained appearance where it occurs interstitially to the quartz. The general central position of the galena in the individual bands of a vein and its relation to surrounding comb quartz indicate that most of the galena was deposited as a vein filling. Cleavage control for its subsequent replacement by quartz, ruby silver, and chalcopyrite is very common. The galena is an important vein mineral because it is selectively replaced by the silver-bearing minerals.

Sphalerite. Sphalerite and galena are the most common vein minerals. Only quartz is locally more abundant than the two combined.

Two types of sphalerite are present. A light yellowish-brown resinous variety is restricted to the eastern part of the district, and a black iron-rich variety is generally most abundant in the western part of the district. The black sphalerite is somewhat more widely distributed than the light-colored variety. In the San Miguel mine both types are present. The black sphalerite is found exclusively in association with the "spotted" type of ore (Vein textures, Ore Deposits). Like galena, both types of sphalerite were deposited as vein filling.

Under the microscope both varieties have the typical dark gray color but only the light-colored variety shows a strong internal reflection. The sphalerite generally occurs

with galena. Silver minerals replace galena more extensively than sphalerite. Specimens of dark sphalerite from the western part of the district usually show an emulsion texture with the chalcopyrite. On the other hand sphalerite (light) from the eastern part of the camp is rarely associated with chalcopyrite.

Argentian Tetrahedrite (Freibergite). The principal silver mineral is argentian tetrahedrite, commonly known as freibergite (Palache, et al., 1944). It is generally localized as small patches in the base-metal portion of the vein. In large specimens of rich ore from the Amarilla mine the freibergite is massive in appearance and is closely associated with chalcopyrite.

Freibergite is most commonly found with galena which it replaces. It also occurs in sphalerite and especially along the grain boundaries between aphalerite and galena. Chalcopyrite consistently accompanies freibergite and forms small blebs or islands which may resemble coarse emulsion texture where the chalcopyrite is abundant. In all cases noted, the freibergite replaces the galena or sphalerite. Rarely is freibergite found with arsenopyrite or pyrite.

Some power x-ray analyses were made of the tetrahedrite and it was found that the unit cell dimension had increased because of the larger atomic radius of silver, which substitutes for copper. It is believed that the close association with chalcopyrite may be the result of exsolution

of chalcopyrite from freibergite during the mineralization. The exsolved copper probably is represented by chalcopyrite. Edwards (1947, p. 80) describes a similar but reverse situation in which tetrahedrite is exsolved from chalcopyrite.

Chalcopyrite. Chalcopyrite is the principal copper mineral but it is not abundant except in ores from the western part of the camp, especially from the San Felipe mine.

In polished section the chalcopyrite is seen as tiny blebs or irregular masses as a replacement of pyrite, galena and sphalerite. It is also associated with freibergite and is replaced by ruby silver. The chalcopyrite forms an emulsion texture with the sphalerite.

Ruby Silver Minerals. The ruby silver has been identified by powder x-ray photograph as a mixture of proustite and pyrargyrite. In hand specimens it can be recognized by the steel-gray color and the strong reddish reflection on the broken surface. The ruby silver is not very abundant, and is generally found in the "spotted" ore from the San Miguel mine.

In polished section the ruby silver generally occurs as tiny replacement islands in the galena with which it is very closely related or, as tiny ruby silver-late quartz veinlets cutting across galena or sphalerite. Galena is by far the favorite host mineral for the ruby silver, although some is seen cutting freibergite and chalcopyrite.

Gold. No free gold has yet been reported in the main part of the district although all the assays show a trace of the metal. The gold content of the ore increases to the west but none of the ores within the district could be classified as gold ore. However a specimen of free gold in a gray quartz goundmass which came from the vicinity of the granodiorite stock in the canyon of Rio Pinos, was obtained from H. Linden in 1951. A polished section of the ore showed that the gold occurred interstitially to the early quartz. Some galena, sphalerite, and pyrite were present in the specimen. The gold had a mutual boundary relationship with sphalerite.

Native Silver. Native silver was discovered in 1954 in the lowest level of the Argentina mine which is producing ore from the Argentina vein. No details concerning the occurrence of the native silver are available. In view of the general lack of supergene activity in the district and the depth at which the native silver was found, it is possible that it is of hypogene origin.

Chalcocite and Covellite. The only two metallic supergene minerals recognized are chalcocite and covellite which occur only in specimens of partially oxidized ore from old mine dumps. Under the microscope both minerals fill cleavage planes in galena or form feathery textured veinlets along tiny cracks (Fig. 52). Both minerals are considered to have formed from the weathering of chalcopyrite.

Quartz. Quartz, along with galena and sphalerite, forms the bulk of the vein material. The quartz is of two general types: a dark fine-grained replacement type and a light gray or white comb quartz characteristic of the crustified vein material.

The darker quartz of greenish-gray to gray color is commonly associated with pyrite and silicified breccia. Where dark gray quartz and pyrite occur in the banded veins, they are considered to represent replacement. Scattered base-metal sulphides are generally seen as small specks in the dark quartz, which usually forms along the side of the vein.

The light-colored comb quartz usually occupies the margins of the individual bands. It also occurs as small seams traversing the earlier bands. The quartz commonly has a euhedral shape and the crystals average 2 to 5 millimeters in length. Under the microscope the crystalline nature of the fine-grained comb quartz is readily recognized. Late comb quartz veinlets, generally containing some ruby silver or chalcopyrite, transect most of the ore minerals.

Barite. White coarsely crystalline barite is a minor gangue mineral. Generally it occurs in the central part of a comb quartz veinlet as crystals 8 millimeters long where it is associated with galena or sphalerite. The mine dumps and prospects in the northeastern part of the district show more barite than veins elsewhere.

Calcite. The other characteristic gangue mineral

of the veins is white and fairly coarse calcite. Crystals about 10 millimeters across occupy the central part of many comb quartz veins or bands. The calcite appears to be about the same age as the barite but the two minerals are seldom found together. In places minor seams or veinlets of white calcite are seen in the walls adjacent to the veins. The mineral was checked by the oil immersion method and found to be calcite.

Supergene Gangue Minerals: In accessible parts of old mines that have been exposed to a long period of oxidiation, supergene gangue minerals are fairly abundant as coatings on the walls of the mine workings. The most common minerals are white gypsum and a yellowish-brown limonite. A green copper sulfate mineral is also common in the western part of the district where copper is more abundant in the ore. In vein outcrops limonite staining is very common and some jarosite has been recognized.

Paragenesis

The sequence of deposition among most of the vein minerals is readily determined and reflects the rather simple mineralogy of the veins. The ore textures are of the more common type associated with open filling and replacement. The most difficult age relationship to interpret is that of quartz but the banded texture of the veins indicates beyond doubt that quartz was deposited throughout the period of

mineralization.

A chart, (Fig. 43) has been prepared to illustrate the mineral sequence. The sequence is divided into an early and late stage not on the basis of a sharp break in the mineralization but on the basis of the general textural and mineralogical relationships seen in the veins and polished sections. The early stage characterized by the deposition of arsenopyrite, pyrite, galena, sphalerite and quartz accounts for the bulk of the vein material formed at a time when open filling was the dominant process. During the later stage, when the silver and copper minerals were deposited, most of the metallic minerals were formed by the replacement of the earlier metallic minerals.

Arsenopyrite, the oldest mineral in the sequence, is partially replaced by later minerals. Although the arsenopyrite assumes its own crystal form and is fairly resistant, it is corroded somewhat by quartz, pyrite, galena, sphalerite and chalcopyrite. Galena and quartz appear to be most effective in the replacement of arsenopyrite (Fig. 44).

The pyrite is also one of the older minerals in the ore and is corroded and veined by quartz, galena, sphalerite and chalcopyrite. Figure 46 shows quartz and galena veining the pyrite. As a rule the late silver minerals do not replace the pyrite. The arsenopyrite-pyrite relationship is more difficult to evaluate. The pyrite is considered younger than the arsenopyrite and although mutual boundary relationships are generally present, remnants of

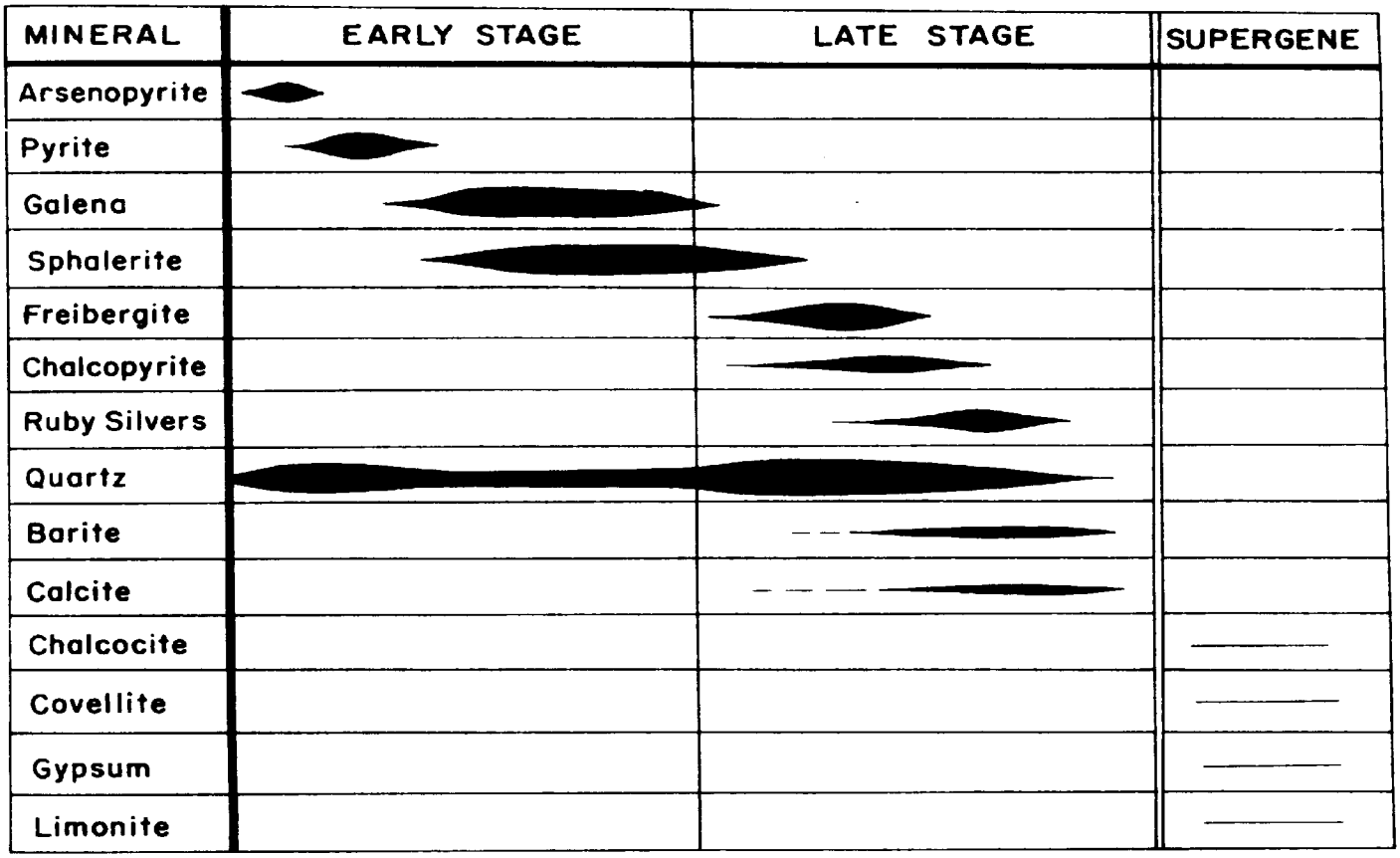


FIG. 43 Graphic representation of the mineral sequence at Topia, Durango, Mexico.

arsenopyrite are more common in pyrite. In a few specimens, the pyrite penetrates into the arsenopyrite with vein-like form (Fig. 45) or replaces the arsenopyrite from the center outward as does quartz which commonly forms a moth-eaten texture with arsenopyrite.

The galena is younger than pyrite, but is replaced or veined by freibergite, quartz, chalcopyrite, and ruby silver. Figures 46 and 47 demonstrate the relative age of galena. The most difficult relationship to establish is between galena and sphalerite. Mutual boundary patterns are most common, but where island-sea textures exist (Fig. 47) the remnants of galena in sphalerite suggest that some sphalerite was deposited after galena. The galena is the favorite host for the silver minerals.

The sphalerite that is later than the galena is distinctly older than the silver-bearing minerals, and is replaced by freibergite, chalcopyrite and ruby silver (Fig. 48).

The freibergite is the first silver mineral to be deposited in the veins. It generally replaces galena along the contact between sphalerite and galena. Most of the freibergite textures observed are of the replacement type in which embayments, corrosion and localization along boundaries predominate. Cross cutting veins are rarely seen. In some places the residual galena forms islands in a sea of freibergite (Fig. 47)

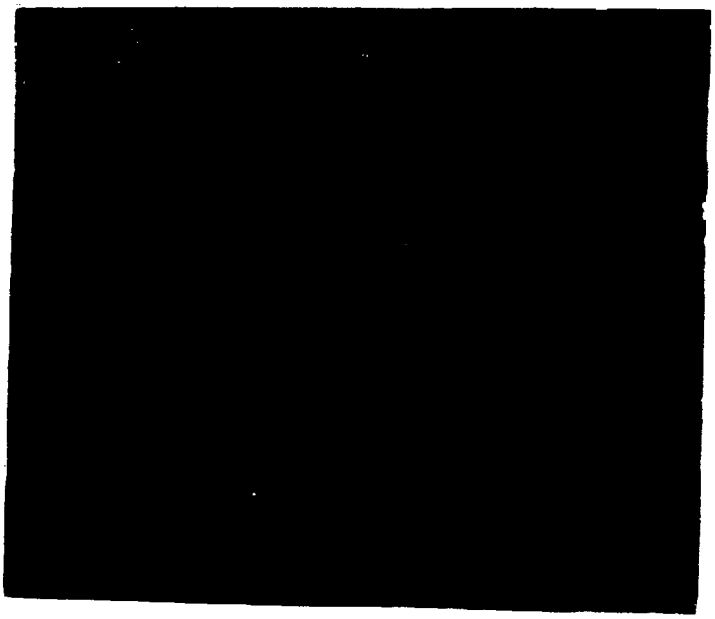
The chalcopyrite, younger than the freibergite, is older than the ruby silver. Figure 49 shows a veinlet of

Figure 44--Arsenopyrite (a) replaced by galena (g) in a specimen from the La Perla vein, Tres Varones mine. Wedge-shaped arsenopyrite is corroded and replaced by galena and quartz. X 50.

Figure 45--Arsenopyrite (a)-pyrite (p) relationship in a specimen from the Las Animas vein, San Felipe mine. The arsenopyrite is cut by vein-like pyrite (raised relief). Galena penetrates arsenopyrite. X 50.

Figure 46--Pyrite (p) replaced by galena (g) in a specimen from the La Perla vein, Tres Varones mine. Veinlets and embayments of galena (far left) replace the vertical band of pyrite. Quartz (q) replaces both pyrite and galena. X 50.

Figure 47--Galena (g)-sphalerite (s)-pyrite (p) relationship in a specimen from the Las Animas vein, San Felipe mine. Irregular remnants and islands of pyrite occur in the later galena and sphalerite. The numerous islands of galena in the sphalerite suggests a later age for the sphalerite. X 50.



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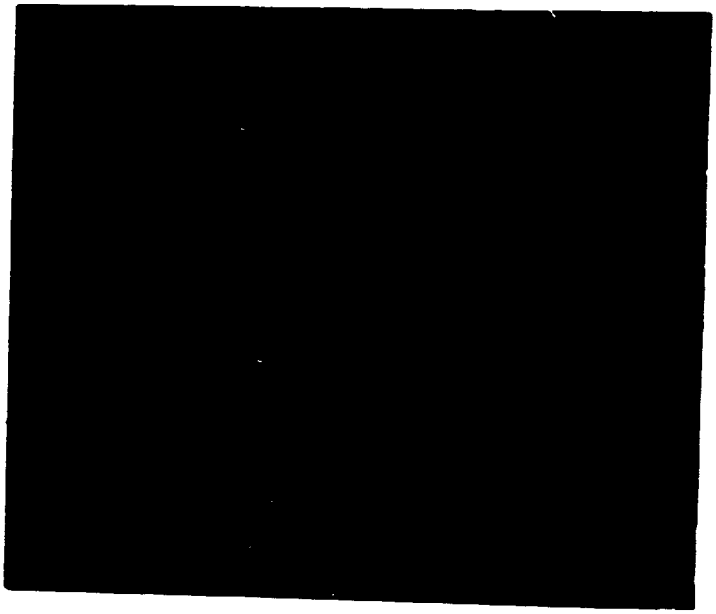

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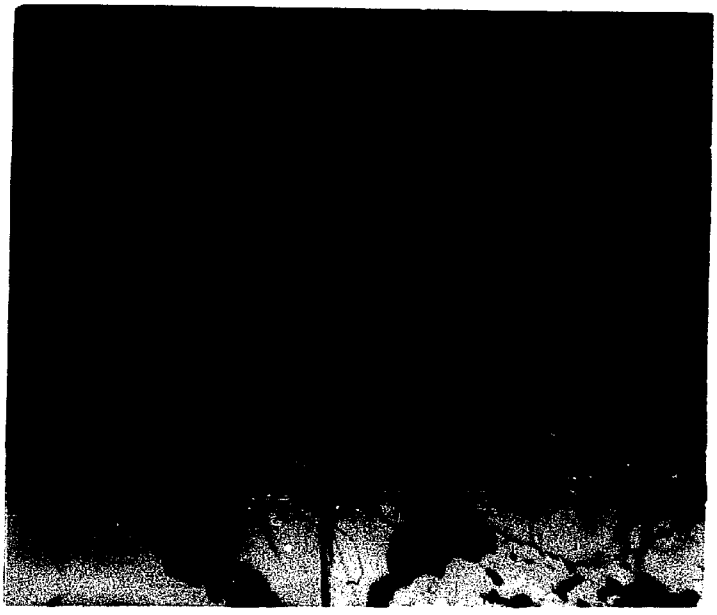

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chalcopyrite and ruby silver which cuts across freibergite and galena. Where chalcopyrite is abundant its textural relations with the other minerals are the same as that of freibergite.

The ruby silver minerals are the latest hypogene metallic minerals to be deposited in the veins. Although they occur nearly always in vein-like form, the veins are generally the result of replacement. In Figure 50, which shows the replacement nature of most of the ore, the ruby silver forms a series of veinlets parallel to the galena cleavage. Its late position in the sequence is also shown in Figure 51, where a veinlet of ruby silver cuts across the chalcopyrite. In some places ruby silver and late quartz occur in veins cutting both sphalerite and galena.

Quartz has been deposited throughout the mineralization sequence. This is best shown by the repeated banding of the ore (Vein textures, Ore Deposits), and by the presence of late comb quartz veinlets transecting the earlier bands. In polished sections the quartz forms either a mutual boundary with other minerals or fills cross cutting veinlets. Because of the outer position of the quartz and the central position of the base-metal sulphide within many of the bands, it is believed that much of the quartz was deposited at an early stage.

Barite and calcite are late in the sequence. Both generally occur as vug filling or as irregular crystalline masses in the central portion of the comb quartz bands. Where seen in polished section, both are associated with

Figure 48--Freibergite (f) replaces galena (g) and sphalerite (s) in a specimen from the Cantaranas vein, San Miguel mine. Small islands and remnants of galena and sphalerite occur in a sea of freibergite. X 50.

Figure 49--Ruby silver (r) cuts freibergite (f) and galena (g) in a specimen from the Cantaranas vein, San Miguel mine. Small veinlet of ruby silver and chalcopyrite trends diagonally from upper right corner across freibergite into galena. X 50.

Figure 50--Ruby silver (r) replaces galena (g) in a specimen from the Cantaranas vein, San Miguel mine. Ruby silver replaces galena along cleavage planes. X 50.



48



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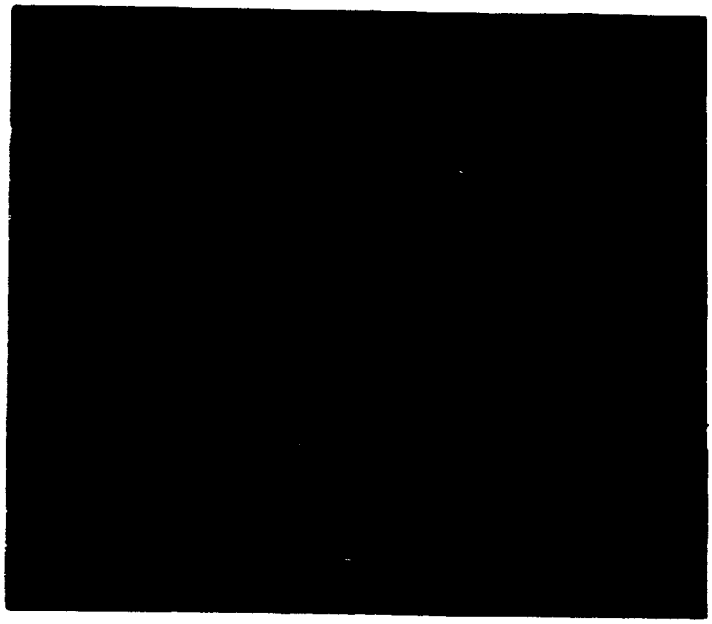

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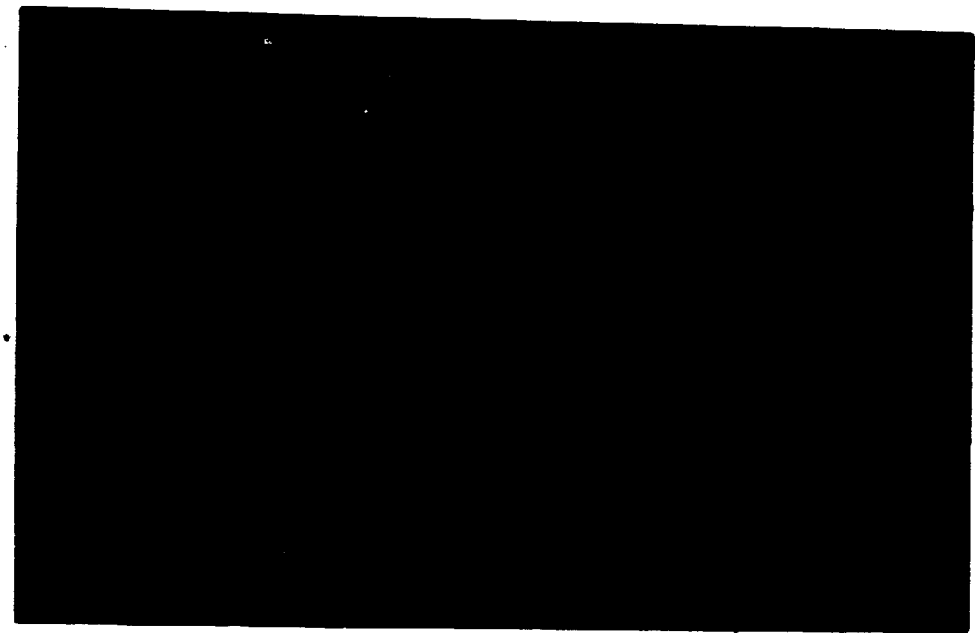
Figure 51--Ruby silver (r) cuts chalcopyrite (cp) and freibergite (f) in a specimen from the Amarilla vein, Amarilla mine. Horizontal vein of ruby silver cuts across freibergite and diagonally trending chalcopyrite vein. X 50.

Figure 52--Supergene covellite and chalcocite in a specimen from the Las Animas vein, Olivia mine. Feathery veinlets of covellite-chalcocite (dark gray) trend in all directions across galena (g), sphalerite (s) and a diagonal veinlet of chalcopyrite (cp). X 50.



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the late quartz which corrodes and veins the early minerals.

Chalcocite, covellite, gypsum, and limonite are supergene minerals related to the oxidation of the ores. Gypsum is found only on the walls of the old workings along with limonite which stains the walls a yellow-brown color. In Figure 52 the chalcocite and covellite replace galena, sphalerite, and chalcopyrite along contacts, veins and cracks.

MINERAL ZONING

A mineralogic zoning is believed to exist in the veins at Topia but no quantitative data are available to establish it definitely. The basis for belief in the zoning is the variation in the gold and copper content of the ores and the iron content of the sphalerite. In both cases, the lateral variation is expressed in the distance away from the area of the granodiorite stock.

Assays of the ores from the main part of the district north and east of Topia show that the gold content of the ore is very low. The gold content increases west of Topia in the Tres Varones mine and in the San Felipe mine. Individuals familiar with the district report that gold values are greater in the vicinity of the granodiorite of Pinos Canyon to the point where gold is the principal metal of value. A specimen of gray vein quartz containing free gold was obtained from a vein in Pinos Canyon.

The copper varies in the same manner as the gold. The increase in copper assays parallels that of the gold and the greater amount of copper minerals in ores to the west was established by polished section study. Specimens from the San Felipe mine in the western part of the district at an elevation of 1450 meters have an abundance of chalcopyrite. It occurs in large irregular masses or as an emulsion texture with sphalerite. In the eastern part of the district, the chalcopyrite is a minor mineral closely related to freibergite in which it generally forms blebs. Blue-green supergene copper minerals are common at San Felipe and in prospects to the west and at greater depth, but are rare in the main part of the district.

An interesting feature of the Topia ore believed to indicate a zoning is the variation in the iron content of the sphalerite. In a series of mill tests run on ores from various mines, the iron content of the sphalerite was greater in the western part of the district. Sphalerite from the Tres Varones mine west of Topia averages 4% iron, whereas sphalerite from the San Miguel mine east of Topia contains an average of 1% iron. This is substantiated by visual inspection of the ores. Black sphalerite is the rule in the western part of the camp and light-colored resinous sphalerite is most abundant elsewhere in the district. Edwards (1947, p. 68) believes that dark iron-rich sphalerite (marmetite) is deposited at higher temperatures than the low-iron sphalerite.

It is concluded that the lateral variation in the

Topia ore is the result of an increase in the temperature of deposition towards the southwest. This zonal arrangement coincides with the widespread regional propylitic alteration which decreases in intensity away from the granodiorite of Pinos Canyon.

CHAPTER V

ORIGIN OF THE ALTERED ROCKS AND ORE DEPOSITS

INTRODUCTION

Alteration and ore deposition in the Topia district are clearly related and are the result of the same hydrothermal activity. Therefore a better understanding of the hydrothermal process can be realized by discussing the alteration and mineralization together. The best source of information on the nature and origin of the solutions responsible for the hydrothermal activity is a study of the altered rocks.

The favorable geological setting at Topia provides significant information as to the origin of the propylitic rocks and this may be helpful in the evaluation of propylitization in other districts.

THE PROBLEM OF PROPYLITIC ALTERATION

Definition

Propylitic andesites were first described at the Comstock Lode by von Richtofen (1866, p. 15), who used the term "propylite" as a distinct name for the green rocks containing abundant chlorite. Zirkel (1873, p. 83), in his

work on the 40th Parallel Survey, concurred with this view. Becker (1882, p. 88) in a study of the Comstock Lode, recognized that the propylites were not primary but were the result of alteration; subsequent work on similar rocks elsewhere has confirmed this veiw.

Although Lindgren (1900, p. 645) and most of the earlier writers used the term to represent chloritized rocks, Finlayson (1909, pp. 633-34) employed it to describe the altered rocks adjacent to the gold veins of the Hauraki district, New Zealand, and also included altered rocks of the quartz-sericite type. To discuss more specifically the altered chlorite-rich andesites, Schumacher (1912) and Bürg (1931), preferred to use the phrase "greenstone andesite facies" (grünstein-andesitfacies) for the propylites. "Propylite," however, is a simpler term and is accepted today by most writers to identify the altered basic and intermediate igneous rocks, generally of extrusive origin, which are green in color and are characterized by the formation of hydrous magnesian silicates (chlorites) associated with epidote and carbonates. Schwartz (1939, p. 195) in his summary of hydrothermal alteration accepts the above definition, and this is the basis for the use of the term in the description of the propylitized rocks at Topia.

Origin

Propylitic alteration is a very common type found in various geologic settings and several views are held

today regarding its origin. The most common are: (1) origin due to hydrothermal activity and (2) origin due to deuteric activity (autohydration). At Topia there is evidence for both processes. Hydrothermal activity is responsible for the more intense and widespread propylitization whereas deuteric activity (Deuteric alteration, General Geology) is restricted to the lowest degree of alteration found in the relatively fresh rocks of the district.

An important corollary problem is the relation of the alteration to ore deposition. All agree that propylitization is early, preceding the mineralization. Some consider it to be the result of hydrothermal or deuteric activity independent of ore deposition and others consider it directly related to ore deposition.

An excellent summary of propylitic alteration is presented by R. Coats (1940) in his paper on the alteration at the Comstock Lode, Nevada, which is the "type locality" for propylitization. The subject has also been summarized by Bürg (1931, p. 161) who recognized the following types:

1. Origin through dynamometamorphism
2. Origin through post-volcanic action
3. Origin through autohydration.

The development of propylitic rocks through dynamic metamorphism was proposed by Schumacher (1912, pp. 35-36) following a study of the gold deposits of the Siebenburgen near Brad, Rumania. His conclusion was not based on direct evidence but was proposed as a possibility because of the lack of evidence in support of the post-volcanic theory.

Schumacher noted the early age and widespread distribution of the propylitic andesites and was dissatisfied with the post-volcanic origin because there were large areas of altered andesite without any veins. Observing the relatively fresh appearance of the plagioclase phenocrysts, he doubted a late hydrothermal origin, because, if the solutions were hydrothermal, the phenocrysts as well as the groundmass would have been attacked. Noting that widespread alteration was restricted to the older basal units of Tertiary andesites, Schumacher proposed a possible origin for the propylitization through dynamic metamorphism related to the tectonic activity in the Siebenburgen Erzegebirge. However subsequent workers in the Siebenburgen, such as Krusch and Lazarevic, do not substantiate Schumacher's opinion. Moreover, Lazarevic (1913, p. 349) found that the area of propylitic alteration had no relationship to the regional structural trends.

The origin through post-volcanic action is the view most widely held and is accepted by most geologists who have studied propylitization in mining districts. In many of the districts of the United States, such as Tonopah and the Comstock Lode in Nevada, and the Bonanza and Breckenridge districts in Colorado, propylitic alteration is widespread, and in places it is related to veins. Coats (1940, p. 15) believes that propylitization at the Comstock Lode was due to hydrothermal activity independent of and probably antecedent to ore deposition. Kato (1931, p. 85) in studying the veins in the Tertiary andesites of Japan,

considers propylitization to be the first phase of hydrothermal activity. Lindgren (1933, pp. 457-458) states that propylitization generally precedes metalization and considers it a metasomatic process typical of epithermal ore deposition. Several Europeans adhere to the post-volcanic origin. Krusch (1936, pp. 8-10) believes that the alteration in the Siebenburgen, Rumania, resulted from the penetration and soaking by gases derived from a solidifying magma and that it continued after the formation of the veins. Lazarevic (1913, pp. 345-56), who studied the same area, considered the alteration to be a very early process preceding and not always related to ore deposition. Thus there is some difference as to the exact time relationship between alteration and vein deposition, although propylitization is generally considered to be earlier than the ore.

In a review of the propylitic rocks of the Siebenburgen, Rumania, Bürg (1931) concludes they are the result of autometamorphism of the cooling rock. This is equivalent to deuteric activity (Shand, 1947, p. 159) and the result of solutions of local derivation acting upon the early minerals formed from the magma. Bürg considered the presence of altered inclusions of chloritized pyroxenes in the biotite as support for his theory. The autometamorphism of the ferromagnesian minerals to chlorite and the lack of alteration in the feldspars are attributed to the action of water vapor at temperatures from about 500°C to 1000°C. Similar views are held by Niggli (1924, p. 120) and Schneiderhöhn (1928, pp. 404-406) and autohydration appears to be

an acceptable theory to explain a widespread alteration such as at the Siebenburgen. Burbank (1932, pp. 79-80) also believes that autohydration best explains the weak but widespread alteration at Bonanza, Colorado where the field evidence supports a very early age for the process. Coats (1940, p. 11) postulates a deuteric origin for the alteration of the mafics in the relatively fresh Alta andesite at the Comstock Lode. The chloritization restricted to the mafics in the fresh andesites that occupy a large part of the Topia district is best explained by autohydration.

Bürg, Lazarevic, Schumacher and other Europeans drew their conclusions chiefly from a study of the Siebenburgen region of Rumania where the lavas are not well exposed. In the United States and Japan, intense propylitic alteration occurs in geological settings that offer a more favorable opportunity to study the age relationships, and most American geologists, as well as T. Kato (1931, pp. 73-75) of Japan, favor a post-volcanic origin for the intense type of propylitization.

Autohydration (deuteric action) and post-volcanic action differ not so much in the nature of the process but in the matter of timing, that is, whether the alteration occurred at the time of consolidation of the lavas or whether it occurred after the lavas had formed. Another problem that arises if the the alteration is considered post-volcanic is whether the propylitization is closely related to and part of the ore deposition process. Evidence that would be of critical importance would include the

distribution of the altered rocks, the degree of control by such structural features as faults, joints and veins, and the relation of the alteration to the primary features of the lavas such as contacts, textures, and physical properties.

Evidence for the Hydrothermal Nature of the Alteration at Topia

The main propylitic alteration at Topia is of the post-volcanic type and hydrothermal in origin. The evidence in favor of this view may be summarized as follows:

1. The alteration shows a crosscutting relationship in the area of fresh andesite (Plate III), where every vein has a narrow outer zone of propylitic andesite. The alteration that accompanies the veins crosses the contacts of individual members of the Topia Andesite.

2. The crosscutting relationship is equally evident for the regional type of pervasive alteration. This is not restricted to any one member but affects the entire formation in the southwestern part of the district where the altered rocks surround the intrusive. Both the lower and upper members of the formation are altered in this area, whereas in the northern part of the district the same members are not propylitized. The alteration diminishes gradually in all directions away from the intrusive. Only post-volcanic hydrothermal activity can account for such a distribution of the altered rocks.

3. The entire area was fractured after the andesites were deposited and many channelways were then available to control the spread of the propylitization. All fractures seen at the bottom of Rio Topia Canyon within the area of regional alteration are coated with epidote. In the main part of the mining camp the northeast fissures control both the alteration and mineralization. However the pre-mineral Ojeda fault zone, which is mineralized for a very short distance, served as a structural barrier to the spread of the regional type of alteration (Northwest faults, General Geology). The lavas of the Santa Ana member northeast of the fault are relatively fresh, whereas the same lavas southwest of the fault and closer to the intrusive are completely propylitized. Northeast of the fault the tuff units have been selectively altered and the lava units above and below the tuffs are fresh. The greater porosity of the tuffs, which average 10% in comparison to the fresh lavas which average 3%, was probably the controlling factor in the alteration.

The facts enumerated show that the propylitic alteration is later than the lavas and of hydrothermal character. It is, in part, related to the deposition of the ores.

FACTORS INFLUENCING HYDROTHERMAL ACTIVITY AT TOPIA

The geological setting and field relations give some indication of the environmental conditions existing at the time of alteration. Temperature variations, nature of

the solutions, and rock composition were probably of greater importance than changes in pressure. A comparison between propylitization and the green-schist facies of low-grade regional metamorphism gives some additional information as to the intensity of hydrothermal activity.

The high-grade thermal metamorphism at the granodiorite contact where the andesites were converted into a muscovite-biotite-quartz rock is a good indication that the intrusive served as a heat source (Granodiorite stock, General Geology). Because of the relatively poor thermal conductivity of andesite, the temperature would decrease fairly rapidly away from the intrusive and materially aid the development of an intensity zoning.

The andesitic composition of the rocks provided a chemically homogeneous parent material for subsequent activity. The homogeneity in turn emphasizes the importance of the physical condition of the rock and variable factors other than rock composition.

The presence of a large number of openings in the rocks to serve as channelways indicates that an open system prevailed. Although a considerable amount of erosion is demonstrated by the unconformity, the field relations point to a relatively shallow environment for the granodiorite intrusion and related hydrothermal activity (Unconformity..., General Geology). This would indicate that alteration occurred under a light hydrostatic load.

Relatively uniform pressure and uniform rock composition prevailed. Therefore the factors of temperature

and the nature of the solutions played a more important role in hydrothermal activity.

In view of the relative shallowness of the environment, there is a possibility that the mingling of downward moving meteoric waters with the ascending hydrothermal solutions exerted some influence on alteration and ore deposition (Schmitt, 1950). The fact that little change in the mineralogy of the veins can be seen over a vertical range of over 1000 meters leads to two opposing conclusions: (1) the meteoric waters had little influence on hydrothermal activity, or (2) all the alteration and mineralization occurred within the zone of meteoric water. The first conclusion is favored because of the horizontal zoning in the veins as expressed in the diminishing gold and copper content of the ore towards the northeast as well as the lack of pronounced telescoping.

Metasomatic changes in propylitization result in mineral assemblages resembling those of greenschist facies. Regionally metamorphosed basic rocks (greenschists) are characterized by albite, chlorite, and calcite at the lowest grade and by albite, chlorite, and epidote at the next higher grade (Harker, 1950, p. 280). The basic rocks contain adequate amounts of magnesia, lime, soda, iron oxides, and alumina to provide the constituents for the formation of secondary minerals. The presence of an intensity zoning in the regionally propylitized andesites with a variation from albite-chlorite-calcite in the outermost zone

to albite-chlorite-epidote closer to the intrusive is very similar to the change in grade of the greenschists. The appearance of epidote in higher grades of metamorphism due to increasing temperature (Eskola, 1939, p. 344) is strikingly similar to the role of epidote in the intensity zoning of propylitization, and may indicate that epidote is a higher temperature mineral.

NATURE OF THE HYDROTHERMAL SOLUTIONS

The Alteration Sequence

Propylitization, quartz-sericite alteration, and ore deposition have resulted from the activity of hydrothermal solutions. In considering the nature of the solutions, the spatial relations of the alteration types as well as the mineral sequence must be taken into account. The propylitization, which is most widespread, is considered to represent a relatively mild, pervasive, barren alteration not closely related to ore deposition. The alteration is believed to be the result of leaching solutions that consisted mostly of water and carbon dioxide. The altered andesites exhibit a mineralogical zoning which probably reflects a temperature decrease outward from the granodiorite. However, in the interpretation of the quartz-sericite alteration and vein mineralization two alternatives are possible. One is based on a break in the alteration process, combined with a period of fracturing and faulting; the

other assumes progressive change in a relatively continuing process without a sharp break.

Along all the mapped veins in the fresh rocks of the main part of the district, a symmetrical pattern of alteration is evident. The veins are bordered on each side by a band of quartz-sericite alteration; the sericitized rock is not in direct contact with the fresh rock but is separated from it by a band of local propylitization. This indicates that this propylitic alteration was controlled by the N.60°E. fissures and was closely associated with the quartz-sericite alteration and vein filling. The fissure type control in the main part of the district is distinctive from the controls which account for the widespread regional propylitization. The presence of a localized control for mineralization and accompanying wall-rock alteration suggests that a major break in the hydrothermal sequence occurred after a long period of widespread propylitization. The break was probably structural, later alteration being guided in part by new sets of fractures.

An alternative view for the hydrothermal sequence is possible if the regional and local propylitization are considered to be closely related. The bands of local propylitic alteration have the same mineral assemblage as the outermost low-intensity regional zone and therefore might represent narrow finger-like extensions of regional propylitization along the fissures. This would imply the early existence of the fissures without a major structural break.

However, the mineralogical contrast between the more intense types of regional propylitic alteration and the local propylitic alteration argues against this view. In the high and moderate intensity zones of regional propylitic alteration, epidote is the characteristic mineral. It does not appear in the local propylitic alteration and no epidote bands occur in a consecutive relationship outward from any vein in the main part of the district. The epidote zones are spatially related to the granodiorite intrusive and not to the veins. Wherever a vein cuts across the high-intensity zones of the regional propylitization, the quartz-sericite alteration and vein filling are superimposed on the epidote-bearing assemblages. The contrast in the mineralogy and timing of the regional as compared to the local propylitization may indicate a change in the solutions at the source, or it may reflect an increase in intensity at a later time. The final result in either case is a greater intensity of alteration along the fissures than in the broad propylitized areas. This suggests a break in the hydrothermal activity after an initial period of widespread propylitization. The solutions of the later stage caused local propylitization, quartz-sericite alteration, and vein mineralization along the fissures in the main part of the district and superimposed the quartz-sericite alteration and vein mineralization on the pre-existing regional propylitization.

Although Sales and Meyers (1948) consider the alteration at Butte to be caused by an unchanging ore fluid, this is not believed to be applicable to the entire

alteration sequence at Topia. At Butte, Sales and Meyer postulate that the successive alteration zones parallel to a vein are formed by modifications in the physical-chemical environment within the wall rock during alteration. It is difficult to imagine a huge volume of rock being propylitically altered on a regional scale with only a narrow one to two foot zone of quartz-sericite alteration forming simultaneously along selected fissures. The Butte theory can be applied, however, to the alteration seen along the veins in the fresh rocks of the main part of the district, where the successive bands have a uniform parallel relationship. The constancy along the veins favors the Butte theory during the later stage but it does not apply to the early stage of regional alteration.

Propylitic Alteration

Propylitization as a whole was the most important result of hydrothermal activity at Topia whether distributed over broad areas or localized along the veins. Because of the mineralogical similarity, the regional and local types of propylitization are considered together. Except for the presence of epidote in the regional alteration, the mineralogical changes produced by the solutions operating within their respective areas are similar even though the solutions were active at different periods.

A review of the chemical changes based on data obtained from rock analyses provides some information on

the character of the solutions causing the local propylitic alteration (Chemical and physical changes, Hydrothermal Alteration). Carbon dioxide and water are abundantly introduced together with magnesia and possibly some ferrous iron. A large amount of silica, with some soda and ferric iron and lesser amounts of alumina, potash, and lime are removed. The ferrous iron could have formed at the expense of the ferric iron so that the total iron content may be fairly constant. More is removed than introduced and the solutions are leaching in character. The above changes indicate that the solutions responsible for the propylitization consist essentially of water and carbon dioxide with some magnesia and possibly ferrous iron as well as the leached constituents. Because of the strong leaching of silica and the formation of minerals such as chlorite and calcite, the solutions were probably alkaline (Lovering, 1950, p. 244). Lindgren (1932, p. 457) also attributes propylitization to hot alkaline solutions. The local propylitization is similar in many respects to the fringe type of chloritic alteration seen at Butte (Sales and Meyer, 1948). Because of the abundant development of chloritic minerals and the addition of some magnesia to the rocks, the solutions can be considered somewhat analogous to those which produced hydrothermal dolomitization of limestones at East Tintic, Utah (Lovering, 1949). However the total magnesia added to the rocks at Topia is relatively slight.

Because of the mineralogical similarities, the information obtained from a study of the local type is for

the most part applicable to the regional propylitization. Hot carbonate solutions, leaching in character and operating over a broad area, are believed to have formed the widespread alteration as part of the long initial stage of hydrothermal activity. The variation in the altered rocks, as exemplified by the abundant epidote close to the intrusive and by calcite in the outermost zone, is believed to be the result of the gradual cooling of the solutions outward from the center of hydrothermal activity (Regional propylitic type, Hydrothermal Alteration). The presence of abundant epidote and rare calcite in the high intensity zone does not necessarily mean a decrease in the carbon dioxide content of the solutions. It is believed that at higher temperature the calcium silicate, epidote, and not calcium carbonate is the stable alteration product. According to Eskola (1939, p. 356) and Harker (1950) abundant epidote in the greenschist facies means a higher temperature. The main variable during propylitization was the temperature and not the nature of the solutions. The temperature range of the alteration, however, is not considered to be very great. In districts where propylitization is extensive, the alteration is generally associated with epithermal deposits which are of the low intensity type. According to Lindgren (1932, p. 212), the common range is from 50° to 200°C. In many districts propylitization or similar chlorite-rich assemblages are restricted to the fringe or peripheral areas. This is true at Butte, the Bonanza district, East Tintic, and many other places. Thus

the general environment and occurrence of propylitization indicate that it is a mild type of alteration reflecting relatively low temperature.

The character of the alteration at Topia shows that it is analogous to other widespread barren types, such as hydrothermal dolomitization and argillization seen in other districts. It bears only an indirect relationship to ore deposition, but the local propylitic and associated quartz-sericite zones, which accompany the veins in the fresh rocks, are more closely related to sulphide mineralization and can serve as a local guide to ore.

Quartz-Sericite Alteration

The chemical changes of the quartz-sericite zone show that a large amount of silica and minor amounts of potash and alumina are added; all other constituents are decreased (Chemical and physical changes, Hydrothermal Alteration). This is noted where the local propylitization and quartz-sericite alteration occur in the fresh rocks in the main part of the district. Similar chemical changes are believed to occur where the quartz-sericite alteration is superimposed on the high and moderate intensity zones of regional propylitization.

The nature of the solution responsible for the quartz-sericite alteration is difficult to establish

because both quartz and sericite, the principal minerals, can form over a wide range of conditions. According to Kerr (1950, p. 331) quartz can be deposited under slightly alkaline conditions at temperatures ranging from 250°C to 450°C. Sales and Meyer (1948) note that sericite has been produced from alkaline solutions at temperatures as low as 200°C. Lovering (1950, p. 236) asserts that silica, which shows a great change in solubility with temperature, can precipitate from either a saturated alkaline or acid solution as a result of neutralization or a decrease in temperature. Lovering (1948, p. 60) also believes that the early productive stage at East Tintic characterized by sericite and quartz was caused by solutions which were essentially neutral. The consensus of opinion is that neutral to slightly alkaline solutions are responsible for the quartz-sericite type of alteration. The temperature environment is probably higher than that of propylitization.

When considering the nature of the solution at Topia causing the quartz-sericite alteration where it is associated with the <u>local</u> propylitization in the fresh rocks, it is evident that the solution was saturated with silica which may have been derived from the severe leaching during the local propylitization. A little potash and alumina were added, but analyses show that a considerable amount of both constituents was left in the propylitized rock so that sericite could form with little addition or subtraction. Another clue to the behavior of the solution is the complete removal of all the calcite which was abundant in much of the

propylitic zone. Since calcite generally forms under alkaline conditions (Stringham, 1950), its removal would take place if early alkaline solutions became acid or neutral. Even if the initial quartz-sericite solutions were slightly acid, the removal of the carbonate would tend to neutralize them. In any event the conditions for the leaching of carbonate would tend to favor the precipitation of quartz and sericite, and the removal of calcite lends credence to a possible change in the character of the solutions.

The solutions causing the quartz-sericite alteration superimposed on the earlier regional propylitic alteration produced final results chemically similar to the alteration along the veins in the fresh rocks. This was substantiated by thin section study which showed that quartz and sericite were deposited along the veins whereas epidote, calcite, albite, and chlorite were removed. Since the silica of original rock has been somewhat reduced by the regional propylitization, it is believed that some new silica was introduced into the walls by the quartz-sericite solutions. The silica was probably obtained from hydrothermal activity at depth. Aside from the introduction of silica, the behavior of the solution as a whole seems to be the same as that of the solution which produced the alteration along the veins in the fresh rocks.

It is concluded that the quartz-sericite alteration resulted from the action of slightly alkaline to neutral solutions at a temperature higher than that of the propylitic stage. A reversal in the character of the solutions

from a carbonate-depositing and silica-leaching alkaline type in the propylitic stage to a condition of lower pH in which carbonate and other material were leached and silica deposited, could have initiated the quartz-sericite alteration and mineralization. The reversal may be due to a change in the solutions at the source or the tendency to approach neutrality by the reaction with the wall rocks.

Ore Deposition

The metallic minerals present in the veins were introduced in the following sequence: arsenopyrite, pyrite, galena, sphalerite, freibergite, chalcopyrite, and ruby silver. They were deposited with gangue minerals which consist mostly of quartz of several ages and some late barite and calcite. The mineralogy of the veins indicates that the ore solution was complex and contained the elements: As, S, Fe, Pb, Zn, Cu, Sb, Ag, Ca, Ba, Si, CO_2, and SO_4.

Since most of the ore minerals present are commonly found in deposits formed in epithermal and mesothermal environments, they suggest a temperature less than 300°C. Although arsenopyrite is generally associated with high to moderate temperature deposits, its occurrence in small quantity is not necessarily diagnostic of high temperature conditions. However the occurrence of arsenopyrite early in the sequence and ruby silver late in the sequence suggests deposition on a descending temperature scale. The calcite and barite gangue indicates that alkaline solutions most

likely prevailed during the ore stage. The deposition of quartz throughout the sequence may indicate that the most favorable conditions for the precipitation of silica, that of decreasing temperature and near neutral pH, existed during the formation of the veins. The above relationships suggest that the ores were deposited on a descending temperature scale by a complex solution which was generally alkaline to near neutral in pH. The initial temperature may have been well above 200°C, compatible with quartz-sericite deposition but above the temperature of propylitization.

Summary

Variations are believed to have existed in the character and intensity of the solutions. The regional propylitization is considered an early, mild, widespread, barren alteration resulting from alkaline solutions consisting mostly of water and carbon dioxide. The temperature likely did not exceed 200°C and the propylitic zoning is due to temperature variations within the alteration aureole. Because of the wide extent of propylitization it probably proceeded over a long time. The presence of a later stage of hydrothermal activity suggests a change in the nature and intensity of the solutions which initiated the local propylitic and quartz-sericite alteration along the veins and culminated in ore deposition. The local propylitic alteration, which occurred at this time, is the result of alkaline carbonate solutions acting within the walls

under low intensity conditions and at a greater distance from the fissures. The quartz-sericite alteration adjacent to the fissures is most likely the result of slightly alkaline to neutral solutions at temperatures higher than that of the propylitization. The ore deposits were probably formed by a complex solution which was alkaline to nearly neutral in character. The ore minerals were in all probability deposited on a descending temperature scale in which the initial temperature was higher than that of propylitization. The trend toward a final complex solution suggests changes at the source which may in some way be related to a final surge of fluids containing concentrated metals at the close of deep-seated magmatic activity.

SOURCE OF THE SOLUTIONS

It is believed that the solutions which caused the hydrothermal activity in the Topia district were derived from the deep-seated cooling portions of the magma which gave rise to the granodiorite stock. The several lines of evidence which point to a close connection between the intrusive and hydrothermal activity are the spatial relations of the propylitization, the intensity zoning outward from the granodiorite, and lateral zoning within the veins.

The propylitized andesite forms a huge halo about the granodiorite in the southwestern corner of the district, and the two are closely associated. (See Plate III and Fig. 22.) The presence of an intensity zoning (Hydrothermal

Alteration) in the propylitized rocks further emphasizes the regional control by the granodiorite, which is also slightly propylitized. (See Granodiorite, General Geology.) Coats (1940, p. 15) notes a similar slight alteration in the diorite intrusive at the Comstock Lode and believes that the alteration is not necessarily related to the exposed portions of the stock but to the deeper cooling portions. Santillan (1929, p. 15) and Weed (1902, p. 446) mention the close association between intrusions and propylitic alteration elsewhere in the Sierra Madre Occidental.

A zoning in the veins is suggested by the higher copper and gold content and by the presence of high-iron sphalerite in the southwestern part of the district in contrast to the lower copper and gold with low-iron sphalerite in the northeast. Since the veins trend northeastward away from the area of the intrusive, the zoning is most likely controlled by a gradual cooling of the solutions as they moved away from the granodiorite area. The presence of the zoning points to a source of the solutions in depth in the vicinity of the granodiorite.

The post-andesite age of the granodiorite is established by the contact metamorphism of the andesites. The presence of a cooling post-andesite magma at depth fulfills the conditions generally accepted for subsequent hydrothermal activity and ore deposition.

CLASSIFICATION OF THE DEPOSITS

Although Lindgren (1933, p. 444-63) classified most Tertiary deposits in andesite as epithermal, the silver-lead-zinc deposits at Topia fit more closely a position between the mesothermal and epithermal classification. This intermediate position has been named the leptothermal zone by Graton (1933, p. 187-89).

The deposits at Topia lack the features so typical of epithermal veins such as colloform banding, extremely fine-grained textures, telescoping, and a low ratio of sulphides to gangue. The vein mineralogy, characterized by the occurrence of ruby silver and dominant base metal sulphides, resembles more closely the mesothermal classification.

Graton's leptothermal deposits are characterized by the presence of simple sulphides along with the complex sulpho-salts of silver in a gangue dominated by quartz with carbonates and barite. The sericitic type of alteration is commonly associated with such deposits. Coarse banding along with vugs is quite common and the texture as a whole is finer-grained and more variable than the mesothermal ores. A greater vertical persistence of the veins is common in the group and Graton believes that the lower portions of the Camp Bird vein in the San Juan country of Colorado and the Casapalca deposits in Peru are representative of the leptothermal class. The Topia deposits on the whole have a great deal in common with the above description and for that reason they are classed as leptothermal.

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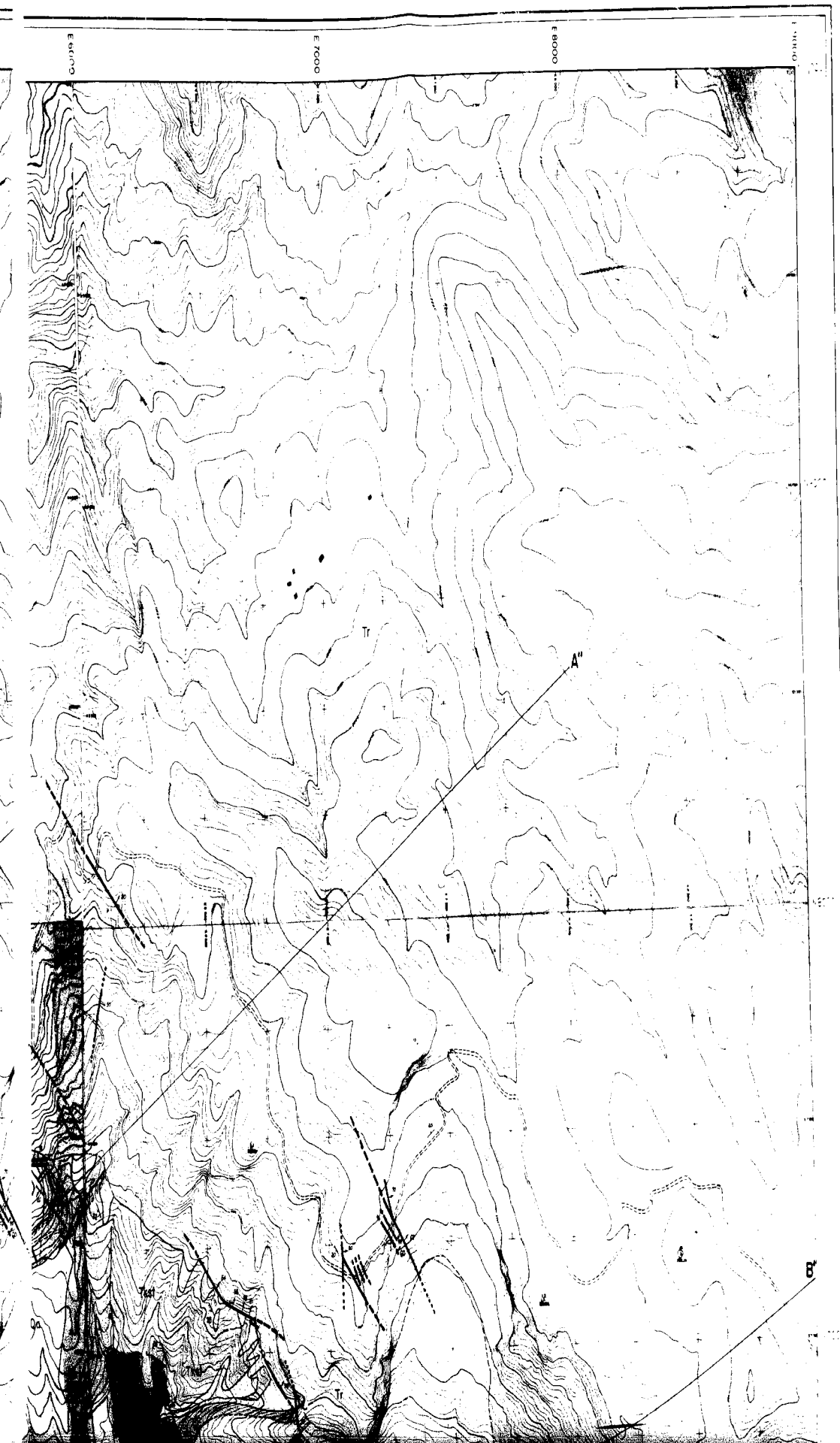


EXPLANATION

TERTIARY TO QUATERNARY

Pliocene to Recent

TQa

Alluvium and Conglomerates

(Talus, stream deposits, heavy soil cover. Buff-colored pebble and boulder conglomerates mostly of rhyolitic rocks, well indurated and terraced in places.)

UNCONFORMITY

MID – TERTIARY

Miocene(?)

Tr

Rhyolite Volcanics

(Light-colored series of interbedded rhyolitic flows, tuffs, agglomerates and ignimbrites with old regolithic soils and tuffs at base.)

UNCONFORMITY

EARLY TO MID – TERTIARY

Eocene to Oligocene

Trd

Rhyolite Dikes

(Light gray to buff, fine-grained dikes with flow banding and a few phenocrysts of sanidine and biotite.)

Td / pd

Diabase Dikes and associated Pebble Dikes

(Greenish-black fine-grained diabase dikes and usually associated with dark brown pebble dikes containing round fragments of basement andesites, rhyolites, ortho quartzites, siltstones and shales.)

Tl

Quartz Latite Dike

(Medium-gray fine-grained porphyry dike with phenocrysts of sanidine and oligoclase, and trachytic groundmass of quartz, feldspar and minor biotite.)



MT. CRUZ TRAMWAY
TOPIA
TQa
Tkst
Tkht
Tkct
Tr
Rio Topia
Victoria
Gregorio
N7000
N6000
N5000
N4000
D
E
B
A
F



fragments of basement andesites, rhyolites, ortho quartzites, siltstones and shales.)

Tl

Quartz Latite Dike

(Medium-gray fine-grained porphyry dike with phenocrysts of sanidine and oligoclase, and trachytic groundmass of quartz, feldspar and minor biotite.)

Tqm

Quartz Monzonite

(Gray-green intrusive rock with phenocrysts of andesine and biotite and fine-grained groundmass of quartz and orthoclase.)

Tkht

Tkst

Los Hornos Member

(Dark purple-gray augite andesite porphyry flows and flow breccia. Tkht is the overlying dark purple tuff and agglomerate unit.)

Tkct'

Tkc'

Tkct

Tkc

Tkt

Undifferentiated Tuff

(Tkht, Tkct, Tkst units combined)

Carmen Member

(Dark purple-gray augite andesite porphyry flows and flow breccia. Tkct is an intermediate dark purple tuff-agglomerate unit. Tkc' is an upper purple-gray andesite flow unit. Tkct' is the uppermost purple tuff-agglomerate unit.)

Tkst

Tkst'

Tkst''

Santa Ana Member

(Dark purple-gray augite andesite porphyry flows and flow breccias, with thick overlying Tkst unit of purple tuff and agglomerate. Tkst' and Tkst'' are dark purple tuff and agglomerate units within the Tks andesite flows.)

Topia Andesite

LATE CRETACEOUS (?) TO EARLY TERTIARY

EARLY T

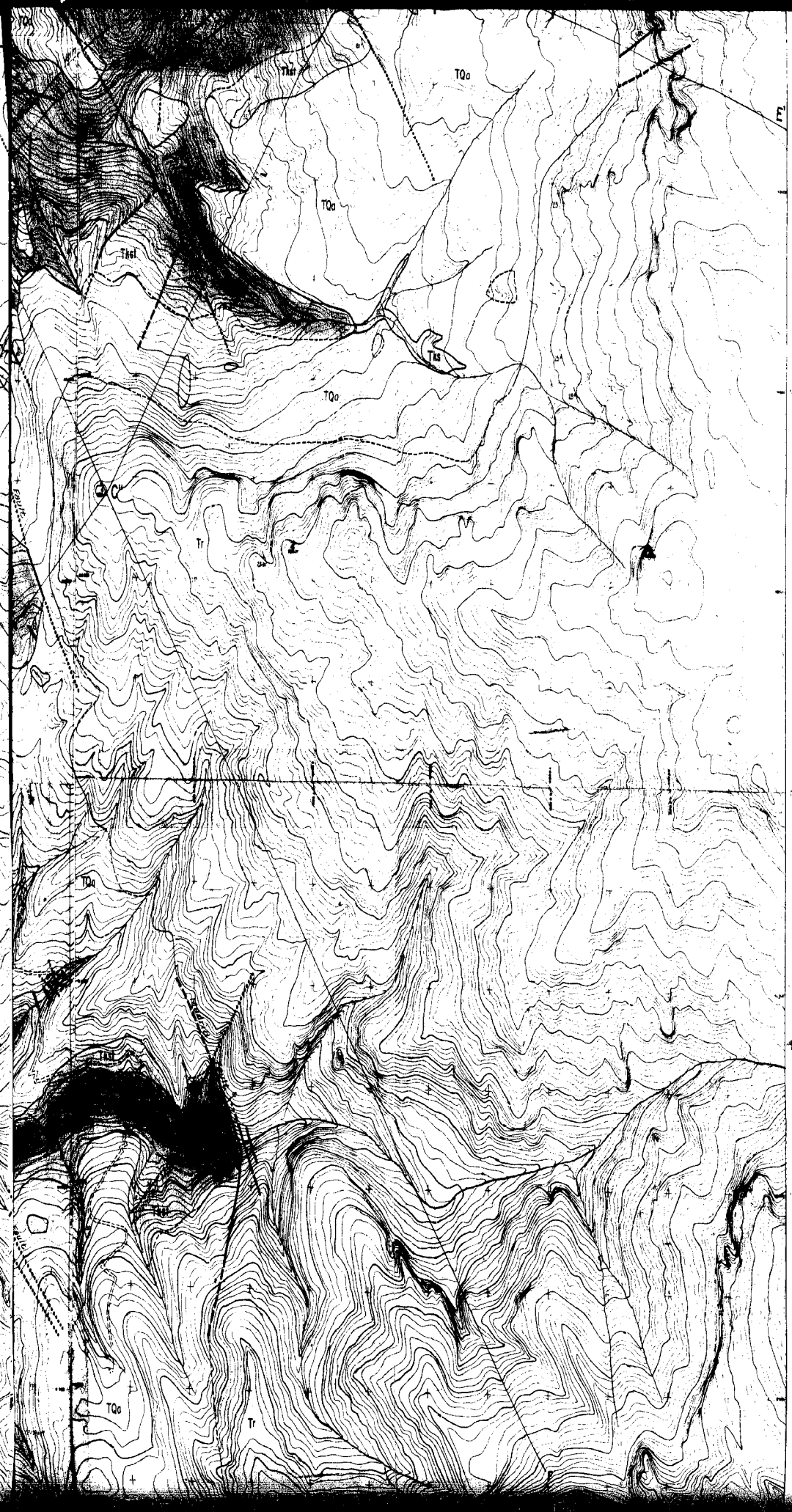
Contact

Indefinite Contact

Strike and dip of foliation or attitude of tuff beds

Strike and dip of foliation and plunge of lineation


N4000
N3000
N2000
N1000
TQa
Tkst
Tkh
Tr
Madrid Fault
Rio



Strike and dip of foliation or attitude of tuff beds

Strike and dip of foliation and plunge of lineation

Fault

Probable Fault

Concealed Fault

Shear Zone

Vein

Inferred Vein

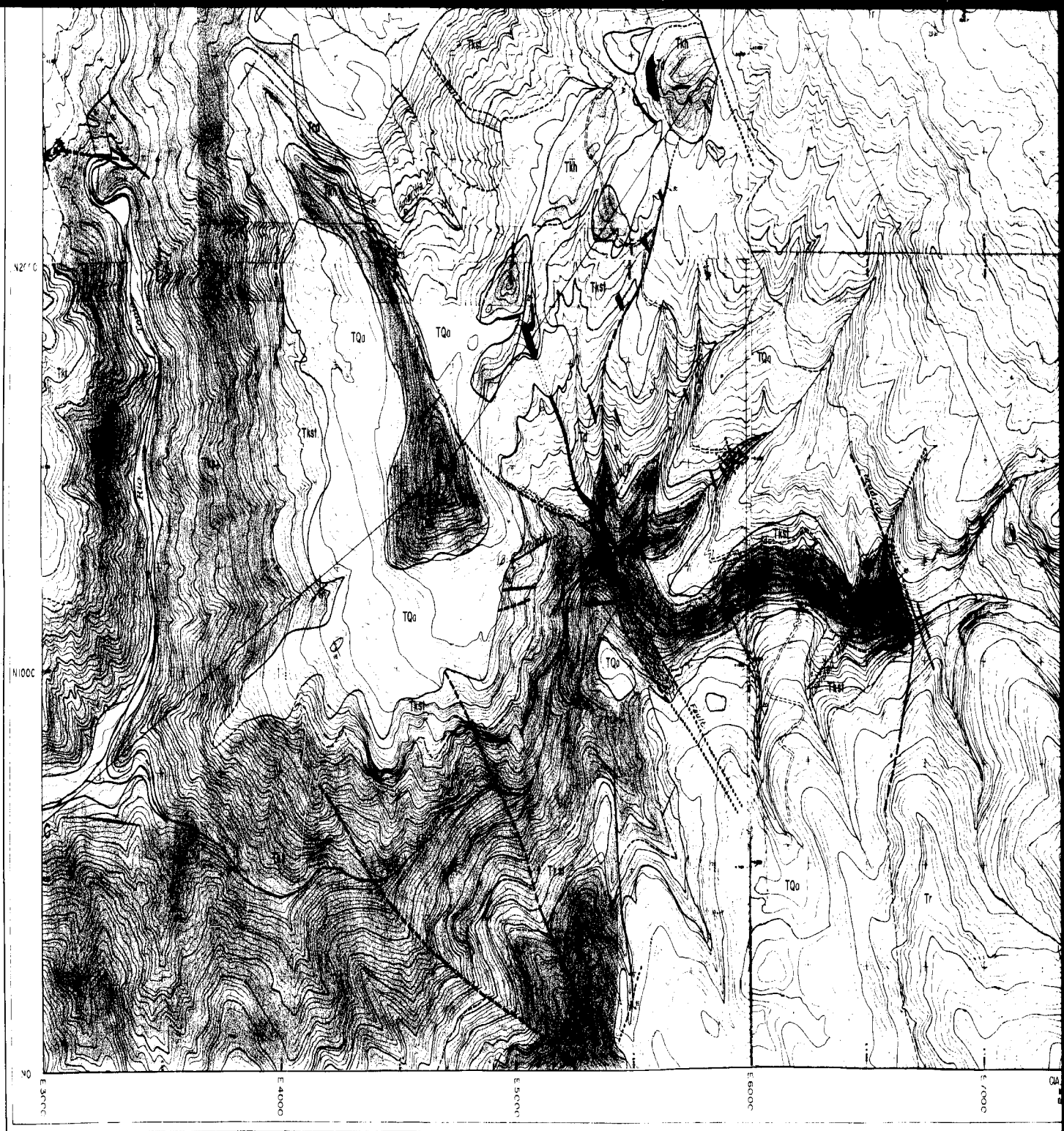
Concealed Vein

Shaft

Mine portal - Adit

Building

Road or Trail



Topographic base compiled from aerial photographs by Cia Mexicana Aerofoto, S.A., 1951.

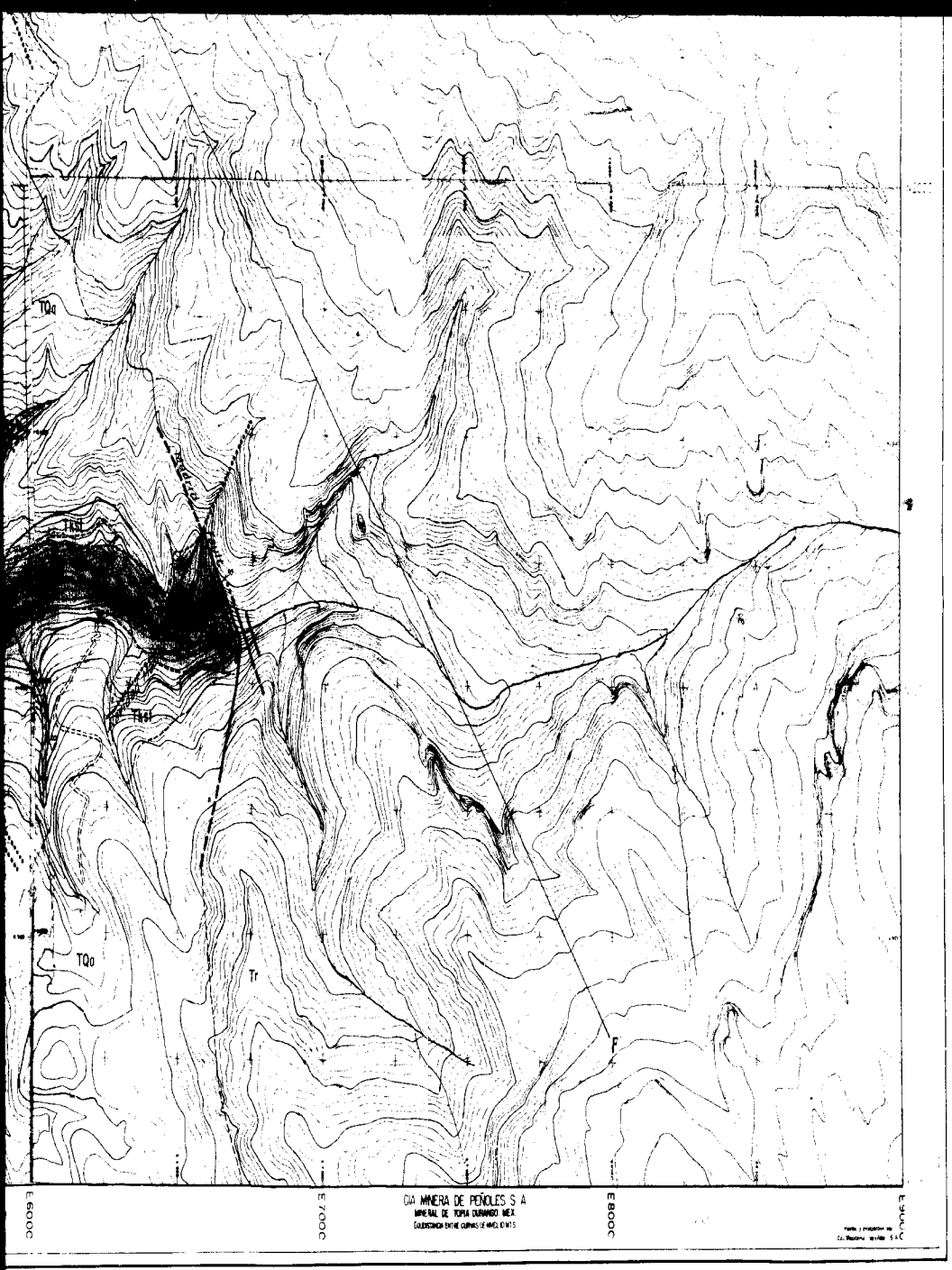
GEOLOGIC MAP OF THE TOPIA MINING DISTRICT DURANGO, MEXICO

Scale: $\frac{1}{10,000}$

0 100 200 300 400 500 1000 meters

0 500 1000 2000 ¼ mile ½ mile mile

Contour interval 10 meters (32.8 feet)



Concealed Vein

Shaft

Mine portal - Adit

Building

Road or Trail

Geology by John Lemish, 19[illegible] - 52

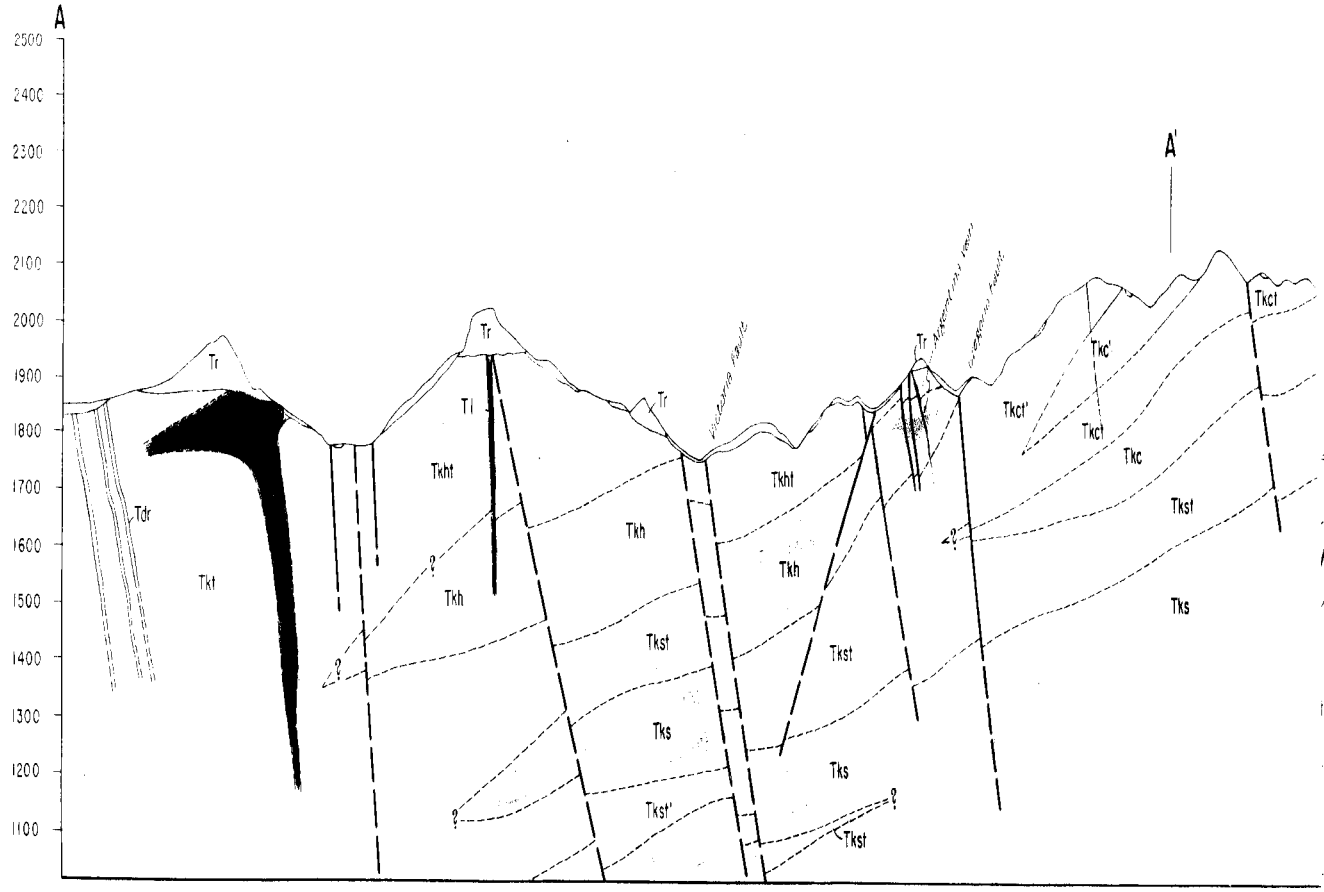
MAP OF THE
ING DISTRICT
GO, MEXICO

le: 1/10,000

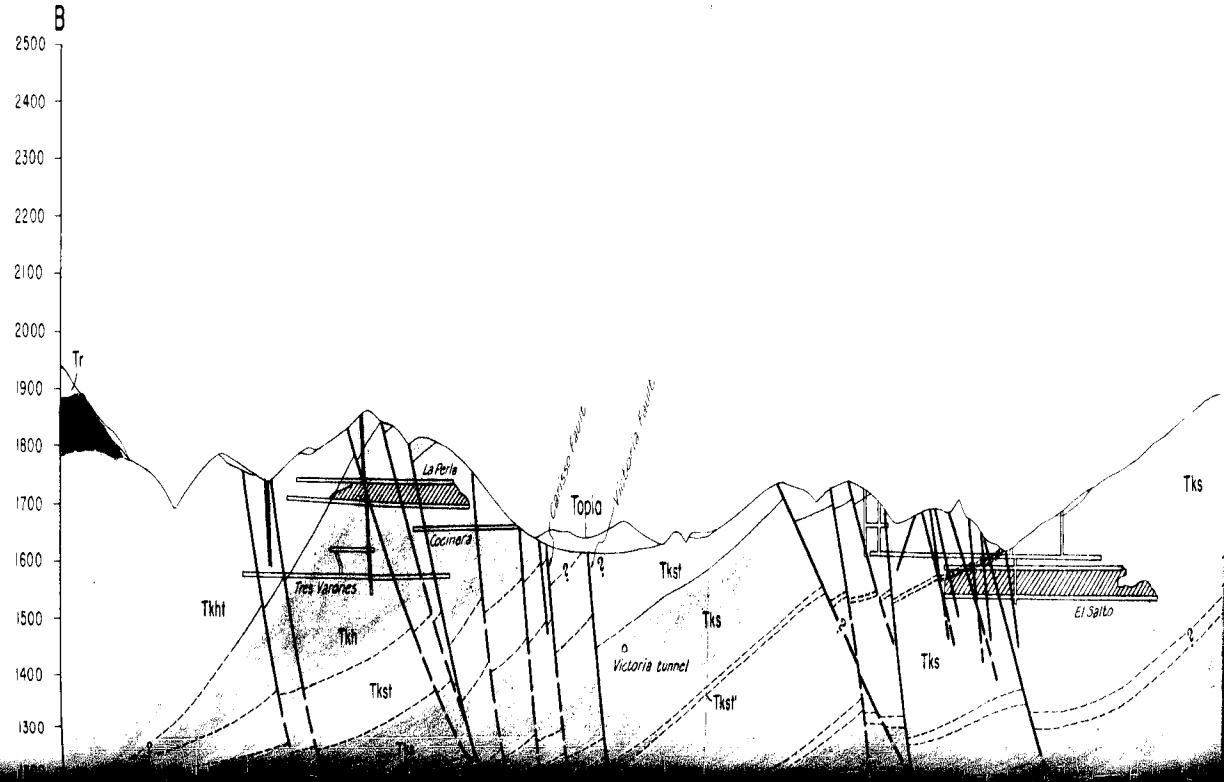
500 1000 meters

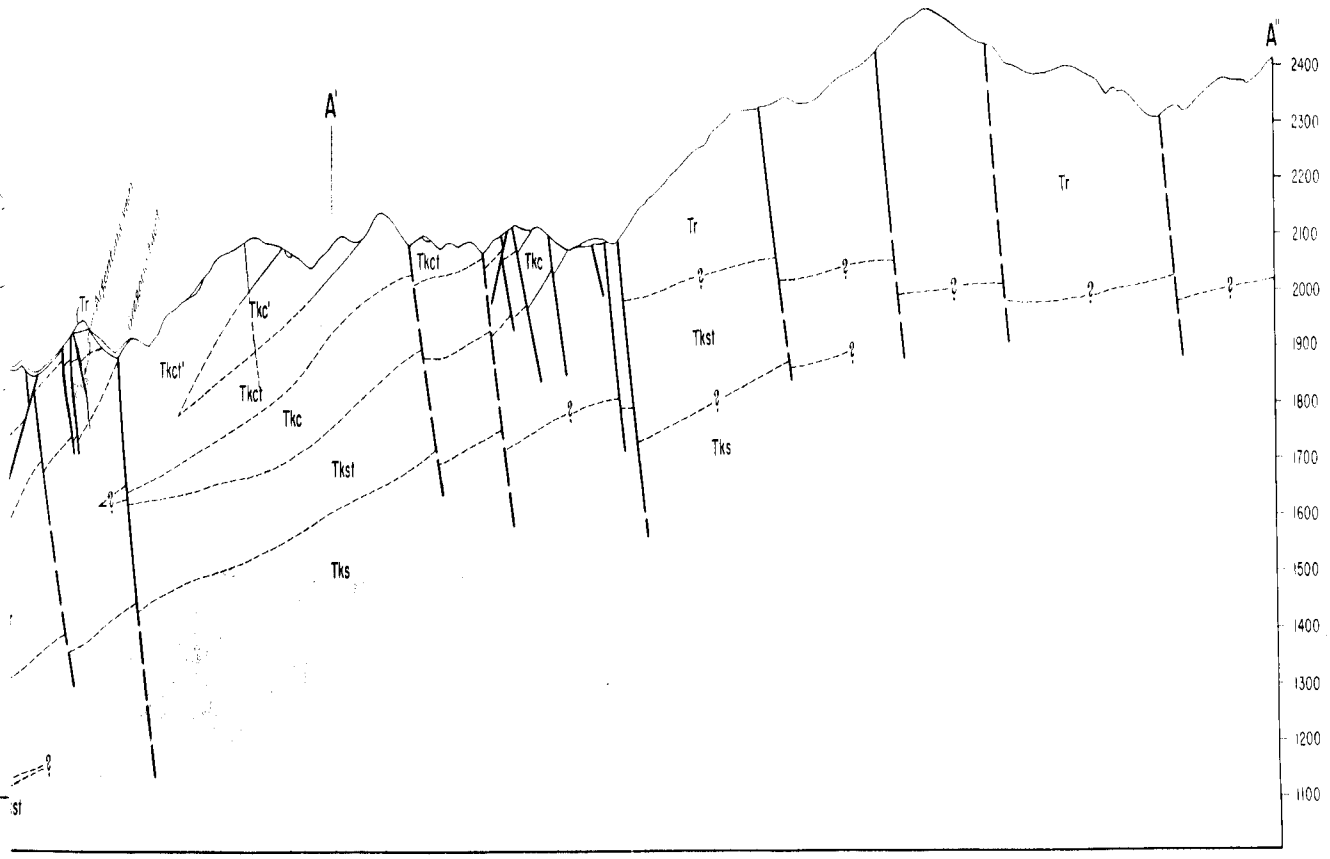
½ mile ½ mile 1 mile

1 10 meters (32.8 feet)

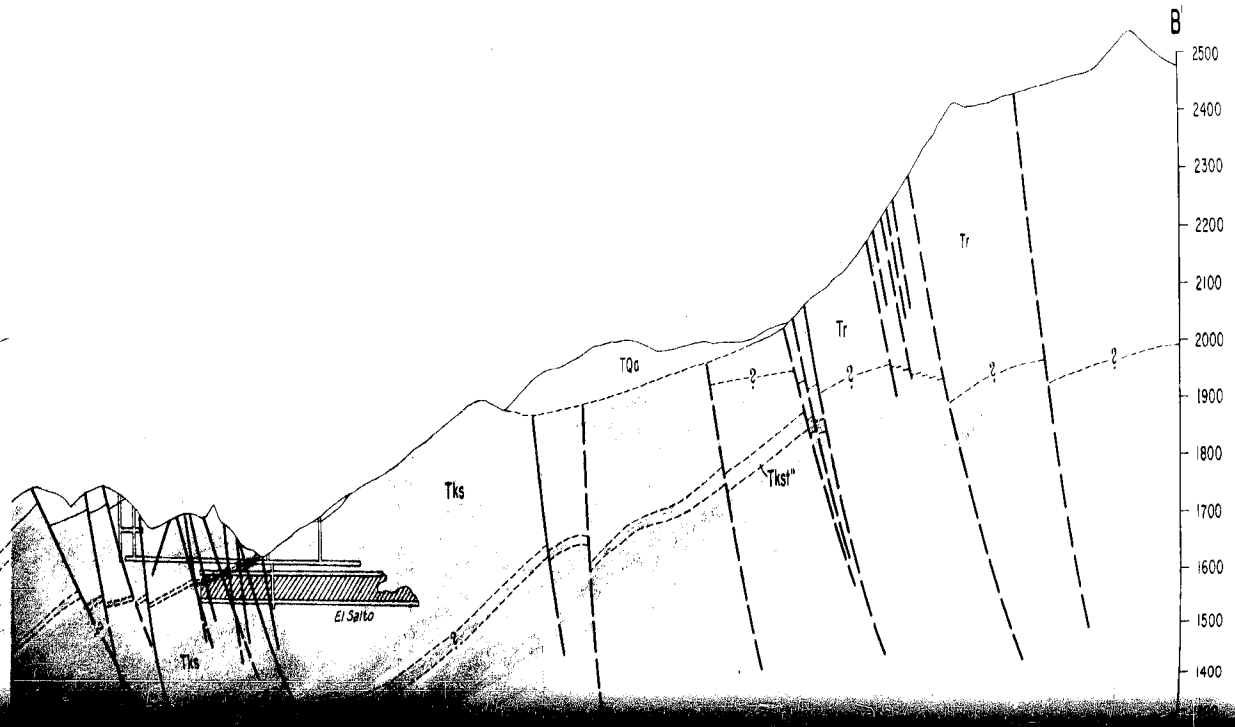


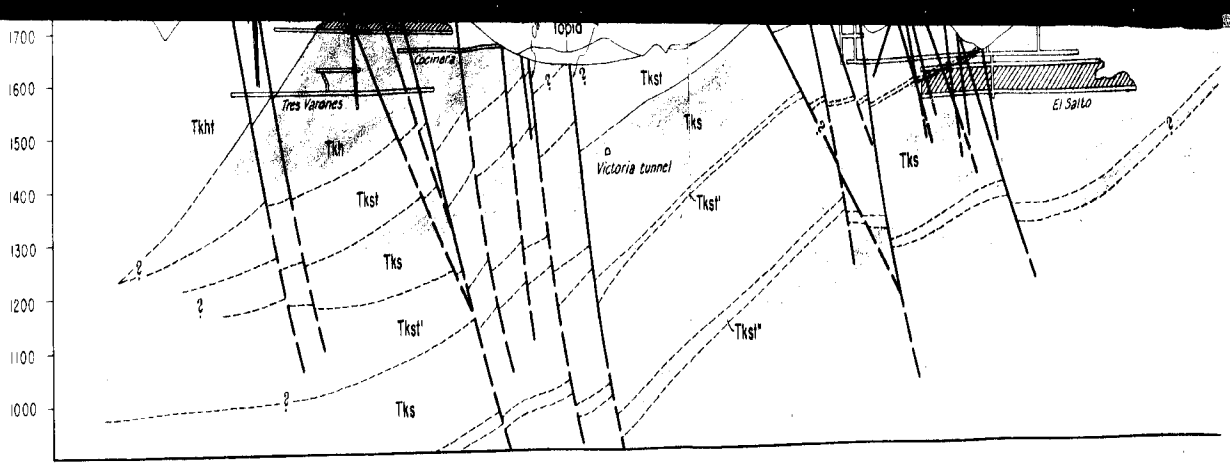
SECTION ALONG LINE A,A',A", PLATE I



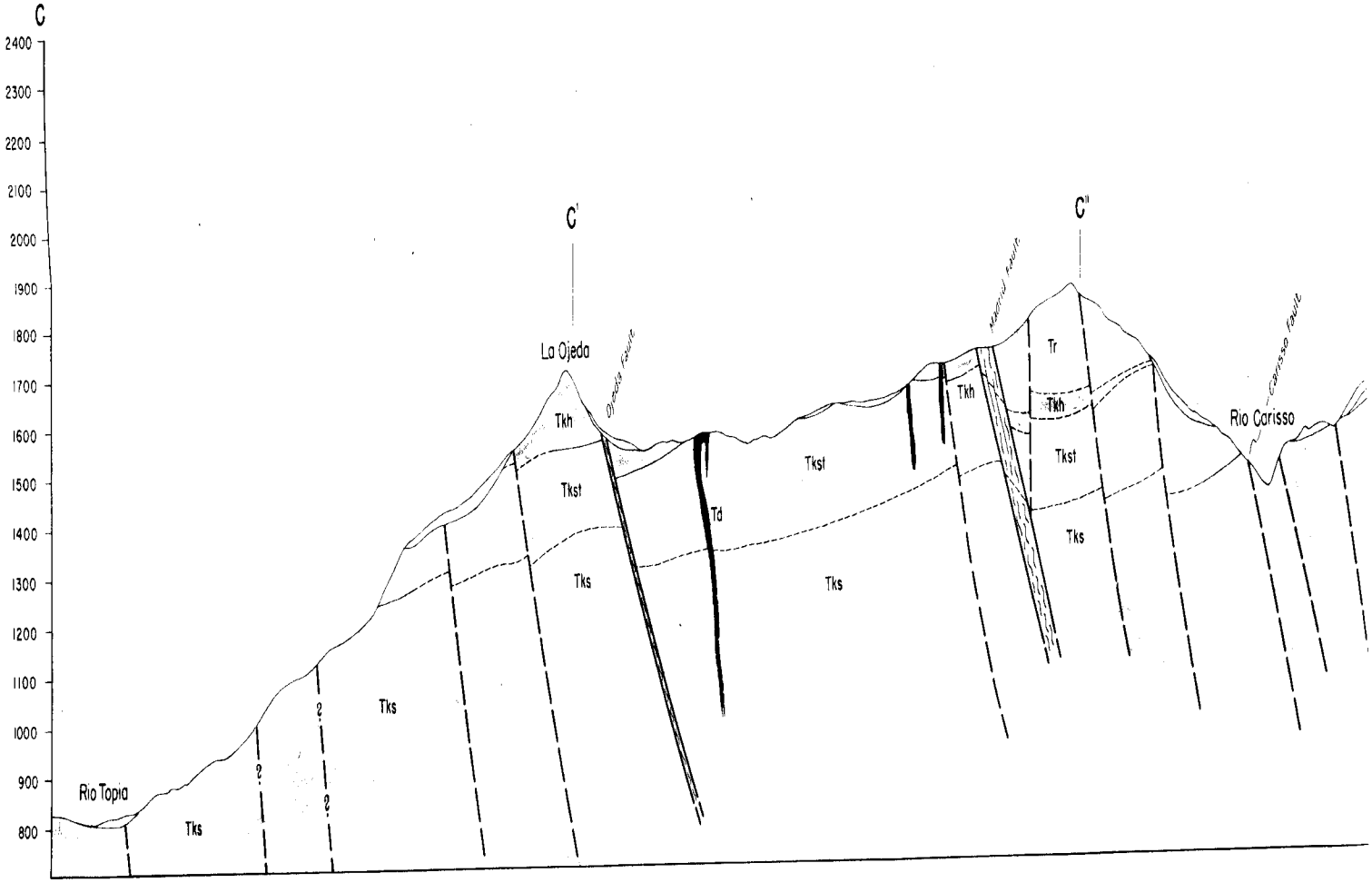


SECTION ALONG LINE A, A', A'', PLATE I

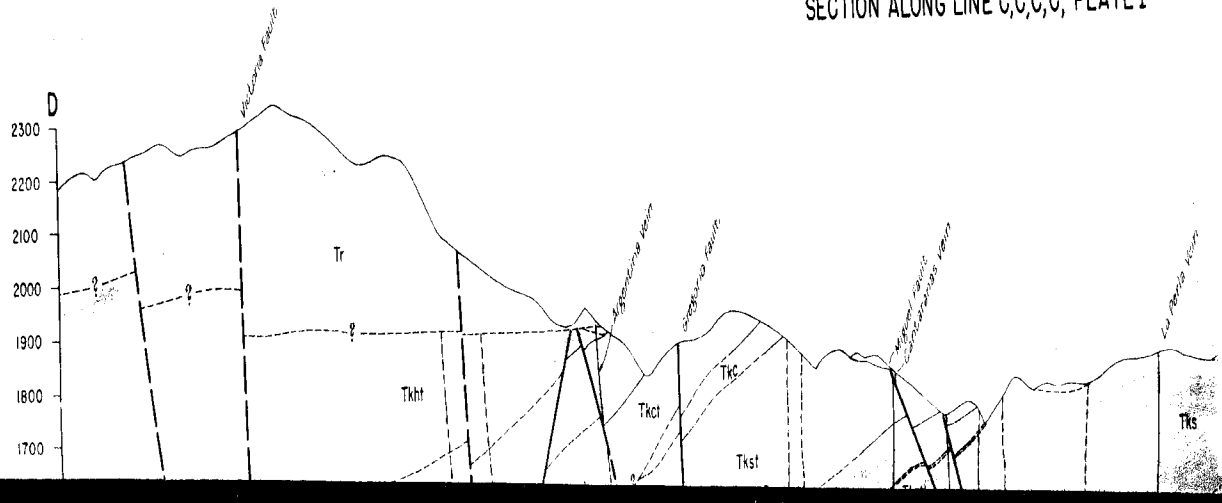


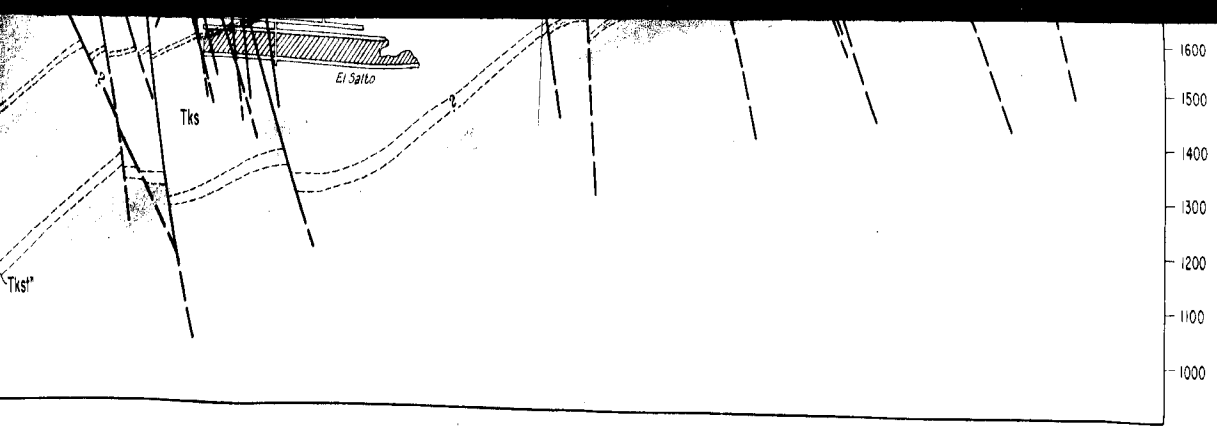


SECTION ALONG LINE B,B', PLATE I

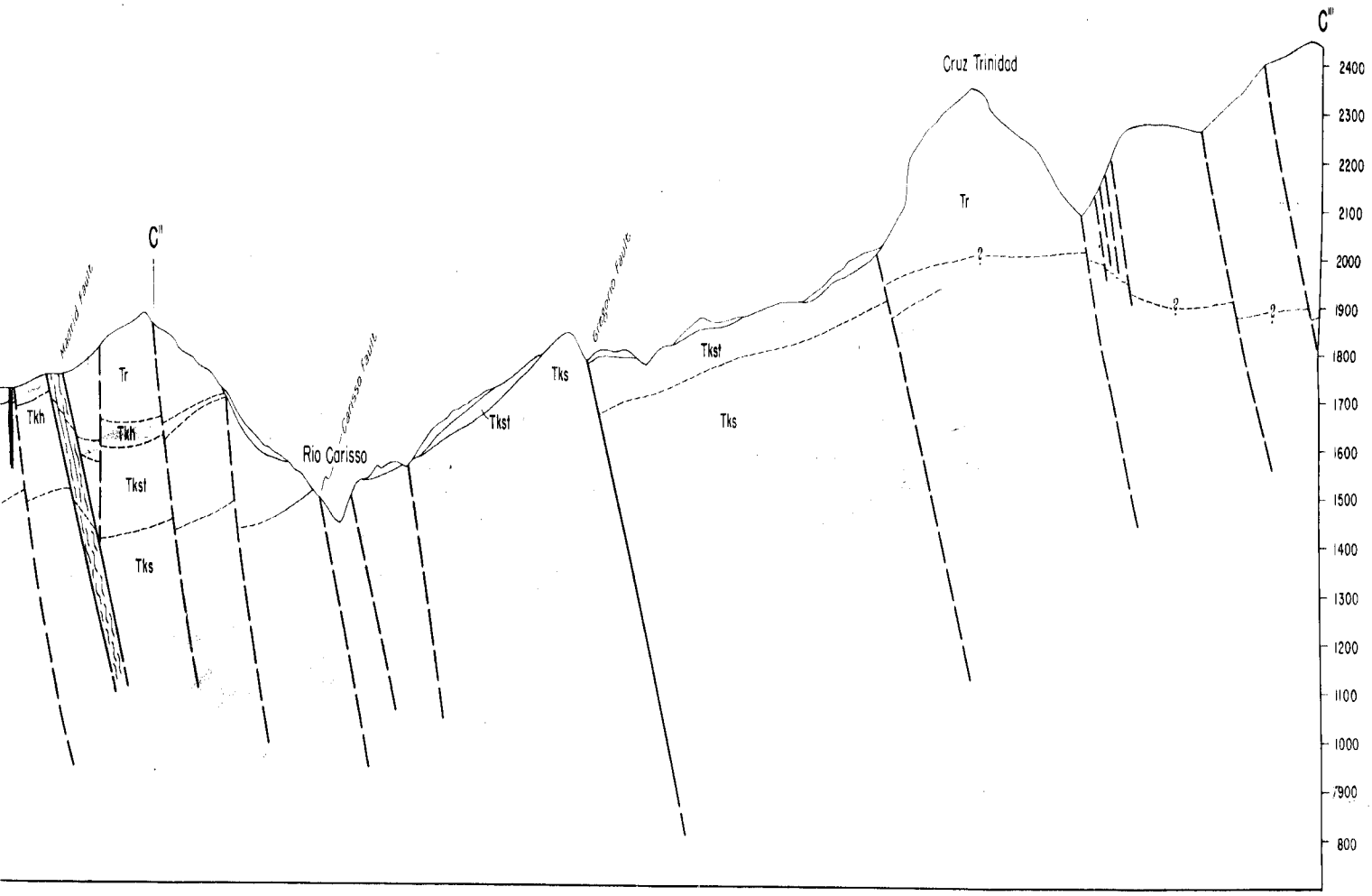


SECTION ALONG LINE C,C',C",C"', PLATE I

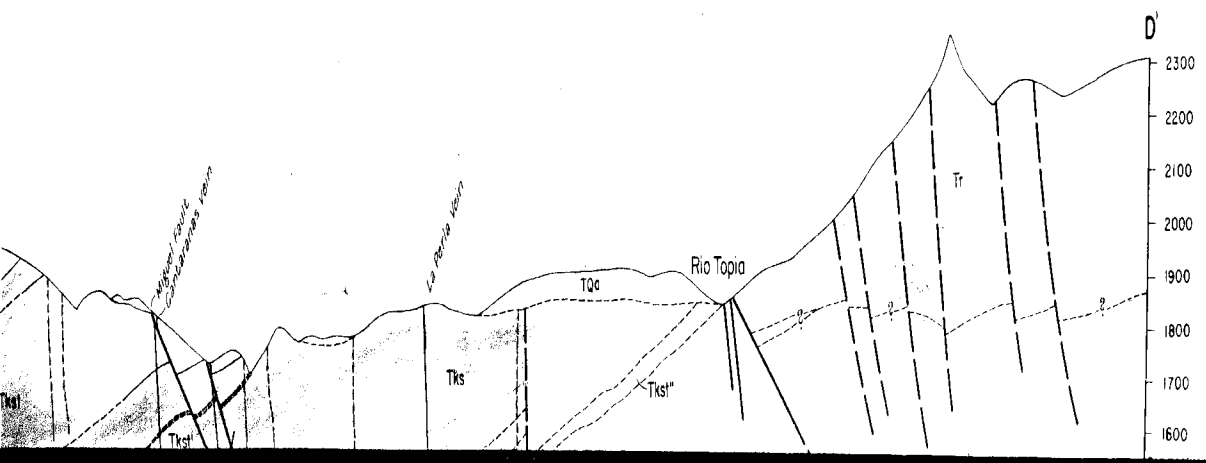


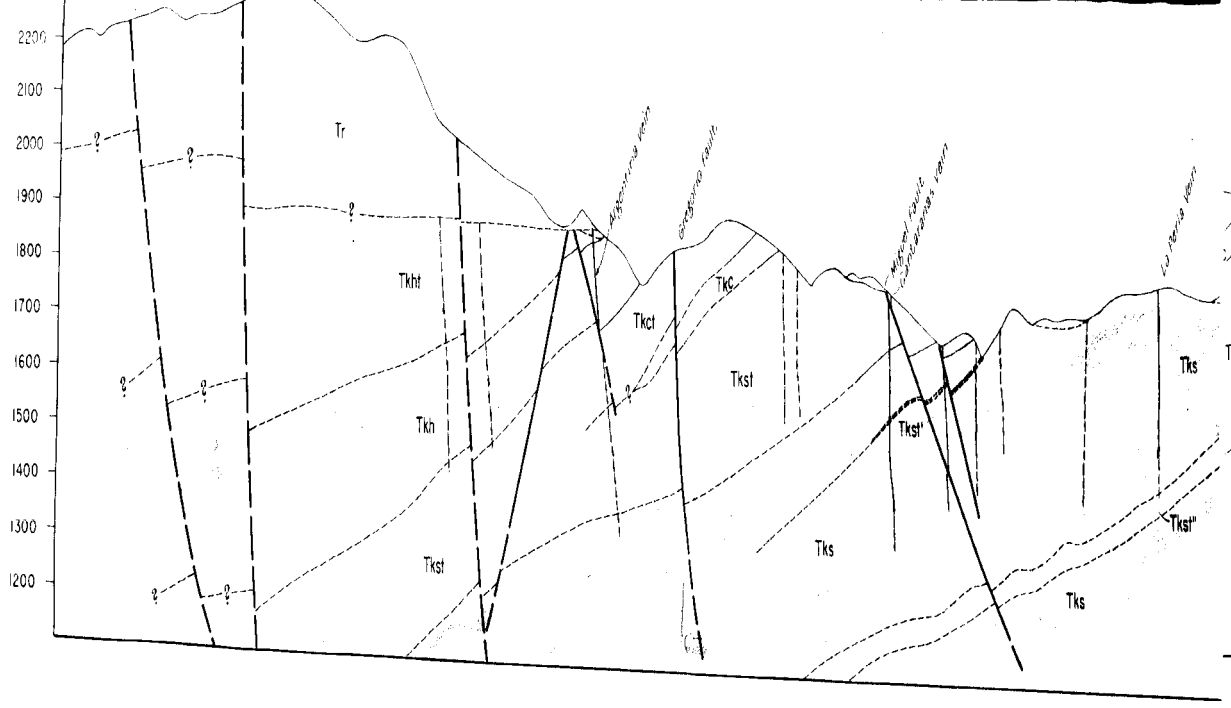


SECTION ALONG LINE B,B', PLATE I



SECTION ALONG LINE C,C',C'',C''', PLATE I

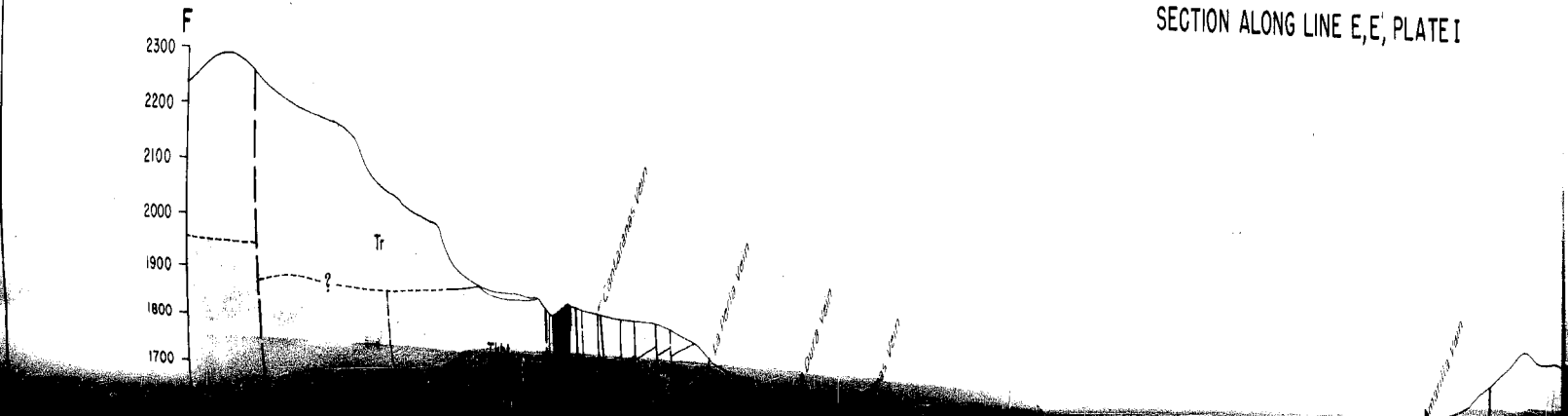


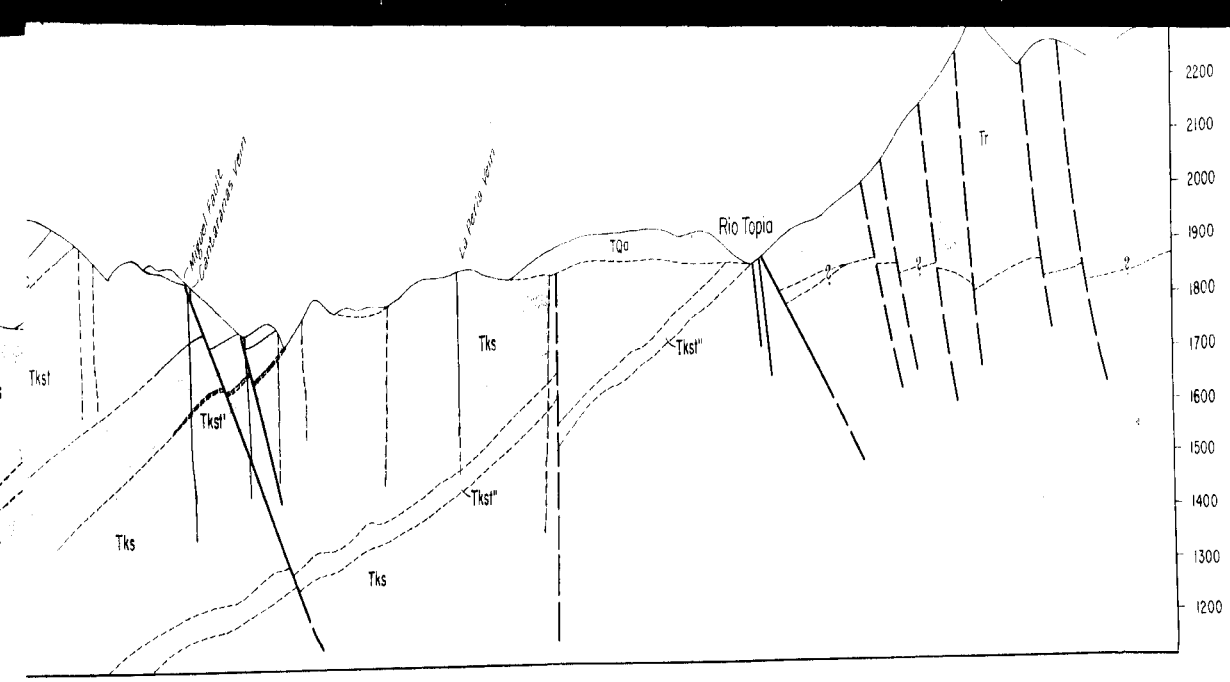


SECTION ALONG LINE D,D', PLATE I

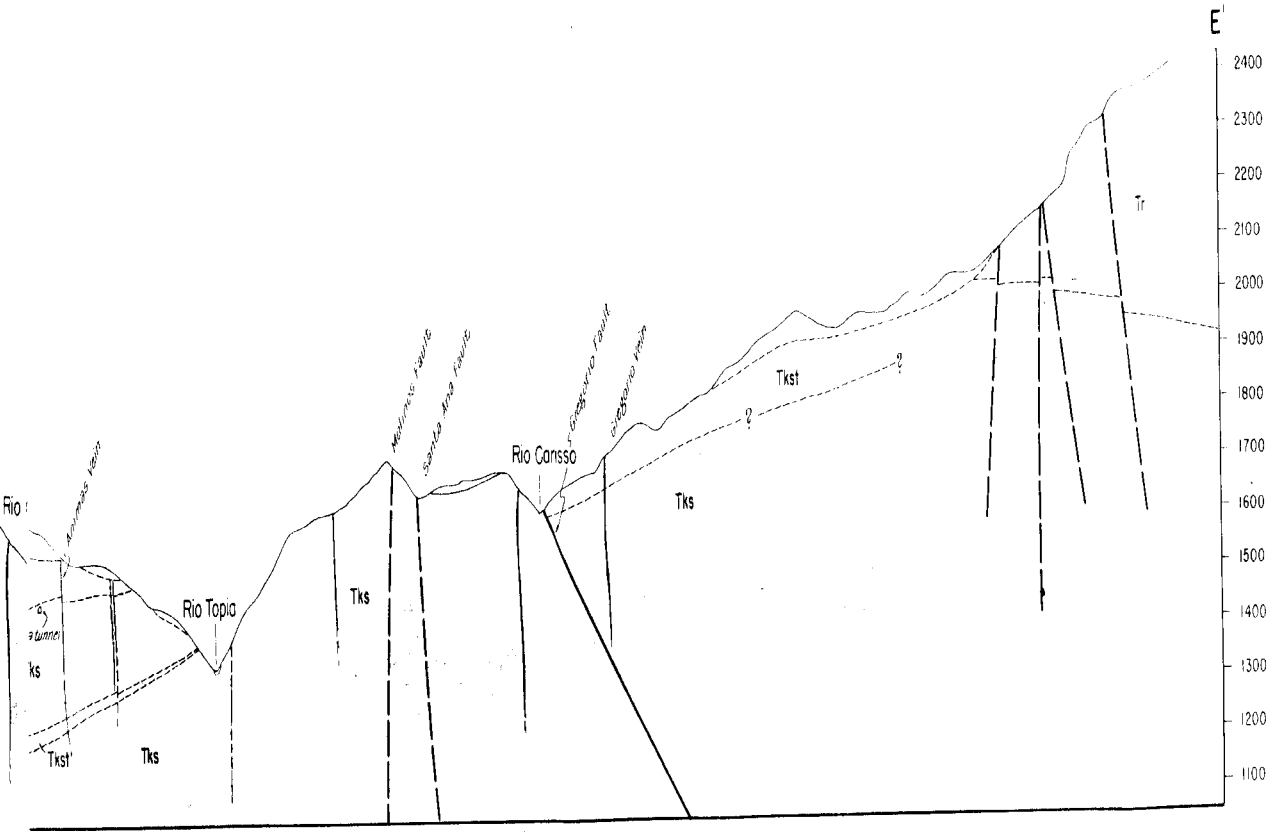


SECTION ALONG LINE E,E', PLATE I



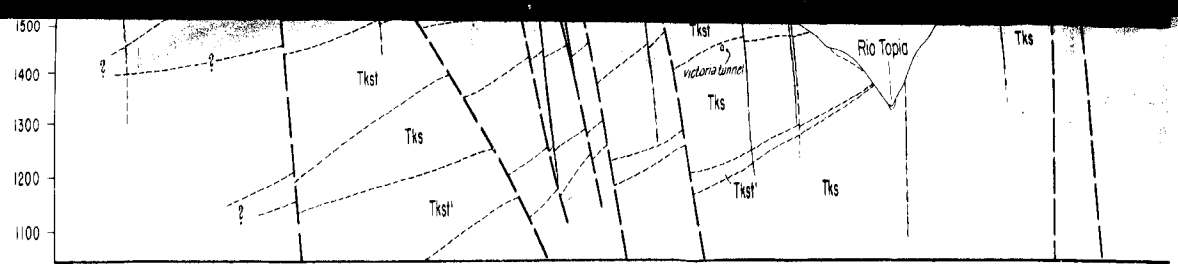


SECTION ALONG LINE D, D', PLATE I

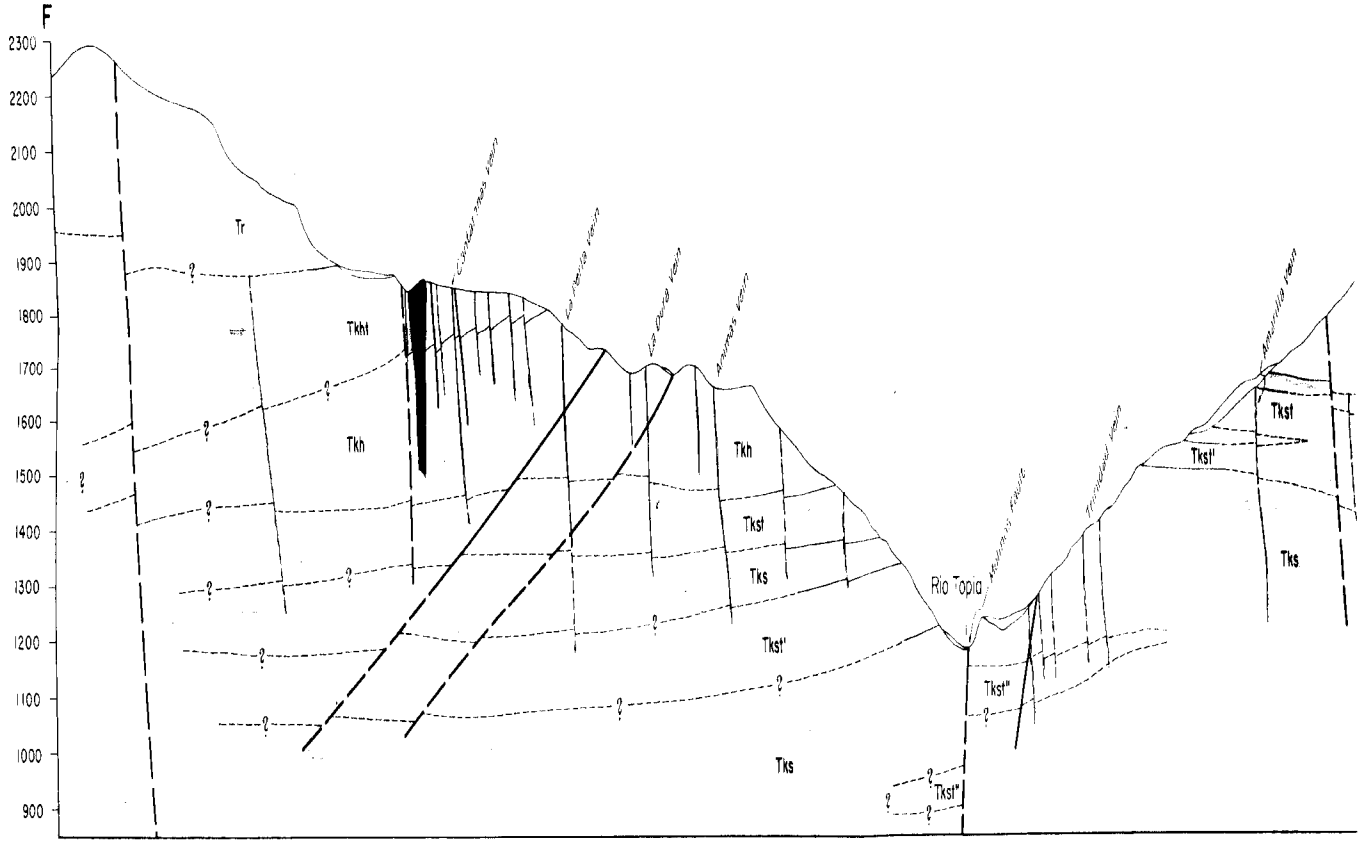


SECTION ALONG LINE E, E', PLATE I





SECTION ALONG LINE E,E', PLATE I



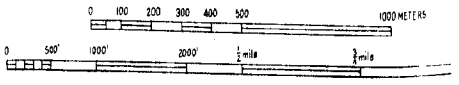
SECTION ALONG LINE F,F', PLATE I

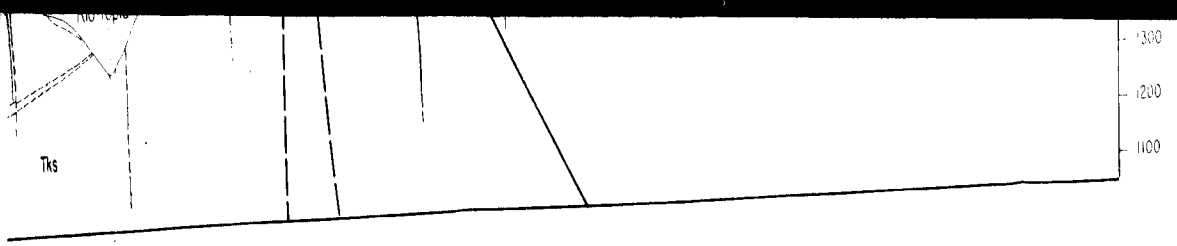
GEOLOGIC STRUCTURE SECTIONS OF THE TOPIA MIN. CT

TOPIA, DURANGO, MEXICO

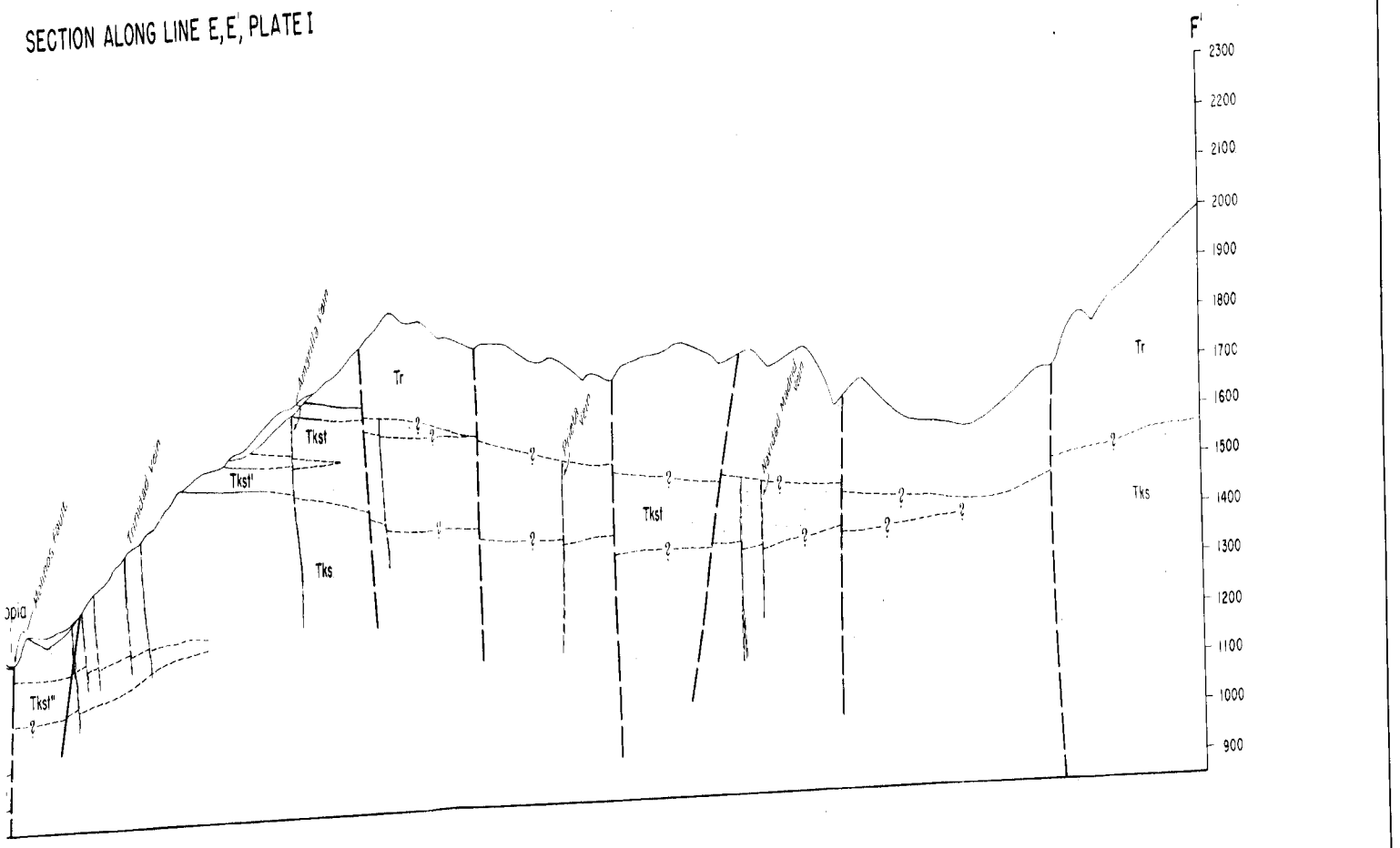
To accompany PLATE I

SCALE: VERTICAL AND HORIZONTAL 1:10,000





SECTION ALONG LINE E,E', PLATE I



SECTION ALONG LINE F,F', PLATE I

CTURE SECTIONS OF THE TOPIA MINING DISTRICT

TOPIA, DURANGO, MEXICO

To accompany PLATE I

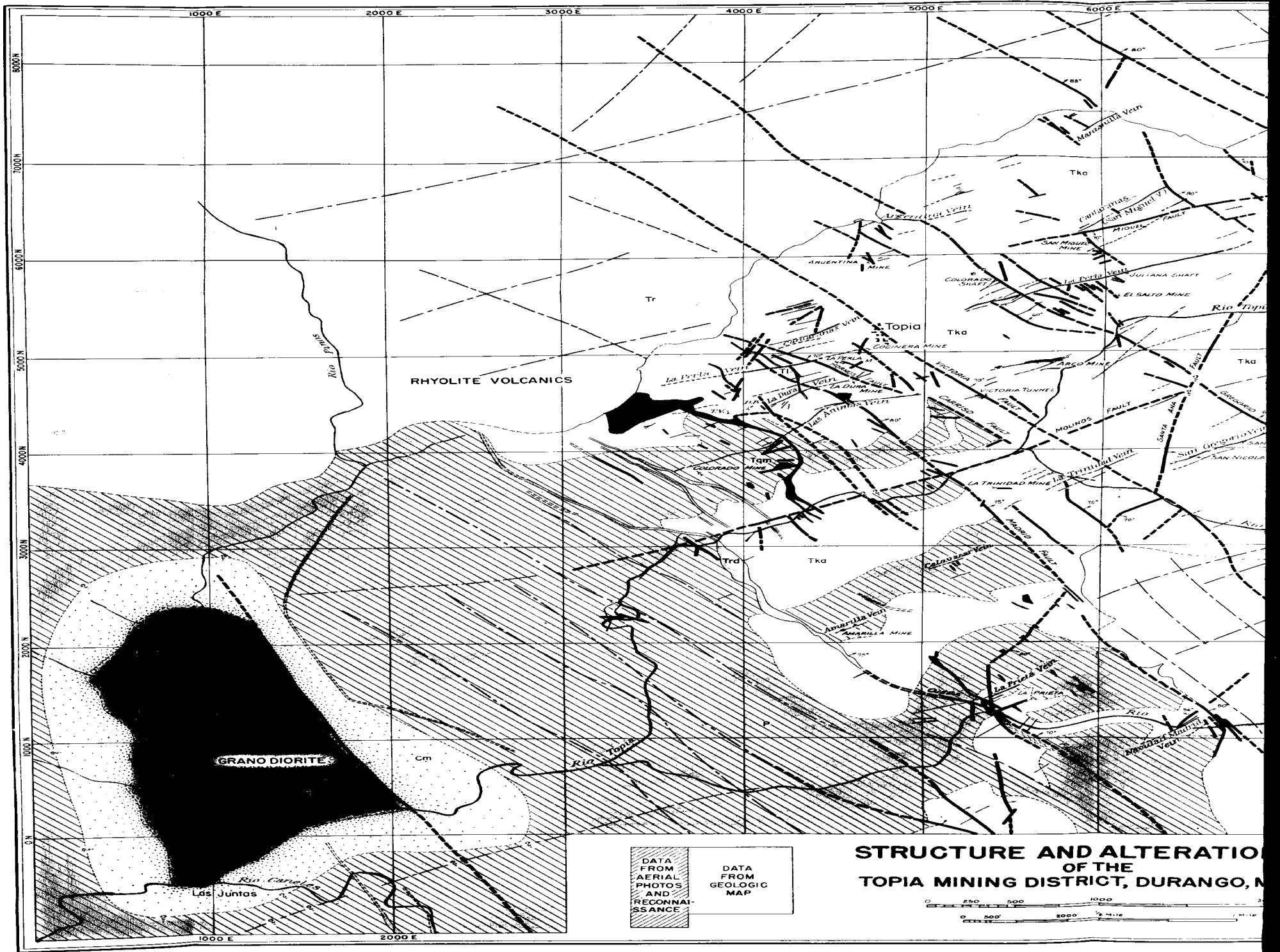
SCALE: VERTICAL AND HORIZONTAL 1:10,000



EXPLANATION

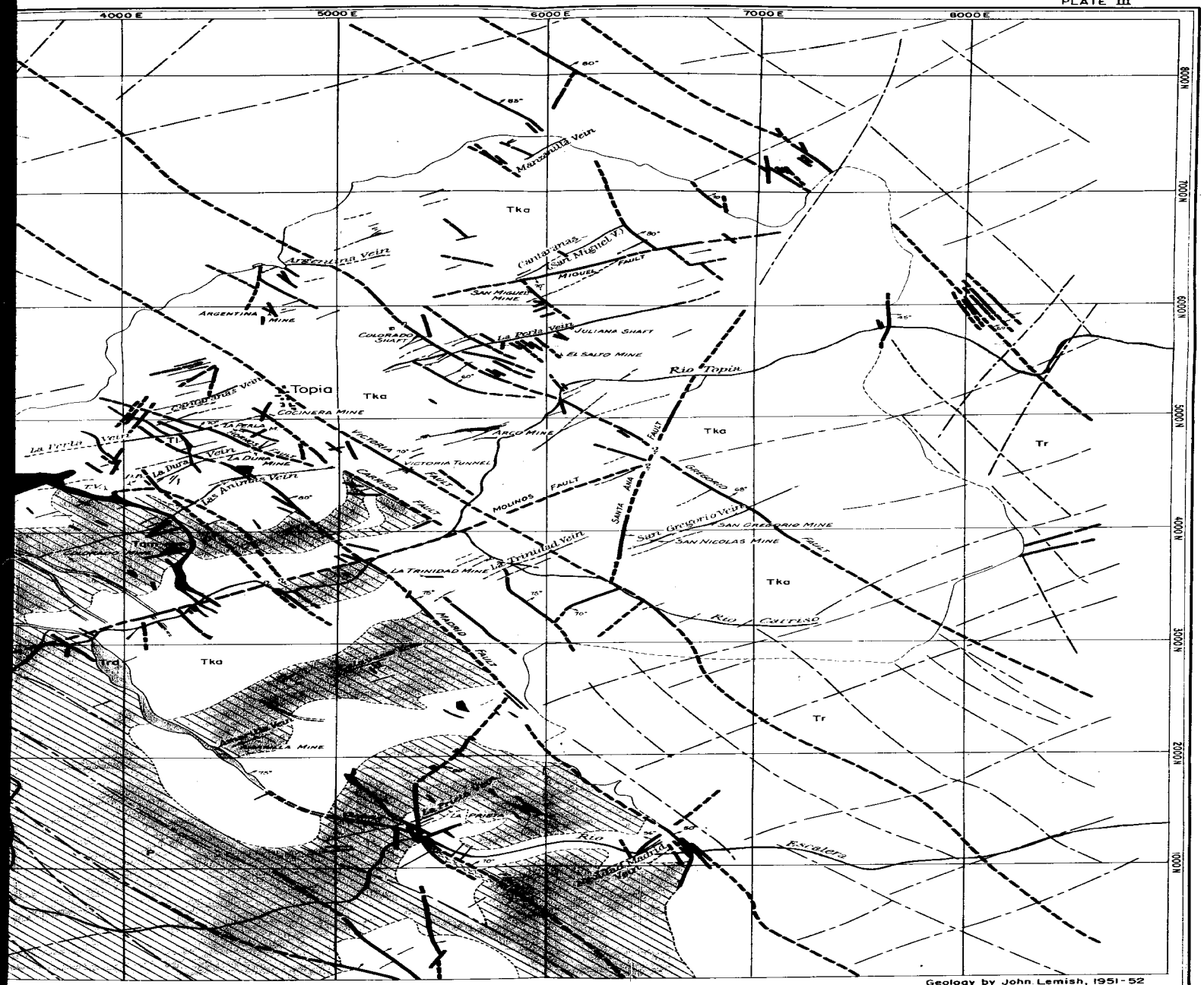
TQa-Alluvium and conglomerate
Tr - Rhyolite volcanics
Tdr - Rhyolite dikes
Td - Diabase dikes
Tl - Quartz latite dike
Tkh, Tkht - Los Hornos member
Tkc', Tkc, Tkct', Tkc' - Carmen member
Tkst, Tkst', Tkst", Tkst- Santa Ana member
Vein
Fault
Mine workings

PLATE II



STRUCTURE AND ALTERATIO
OF THE
TOPIA MINING DISTRICT, DURANGO, M
DATA FROM AERIAL PHOTOS AND RECONNAISSANCE
DATA FROM GEOLOGIC MAP
RHYOLITE VOLCANICS
GRANO DIORITE
Topia
Las Juntas
Rio Pinos
Rio Topia
Rio Canelas
Tr
Tka
Tqm
Trd
Cm
P
Manzanilla Vein
Argentina Vein
Cantaranas (San Miguel V.)
San Miguel Mine
Argentina Mine
Colorado Shaft
La Perla Vein
Juliana Shaft
El Salto Mine
Cocinera Mine
La Perla Mine
La Dura Vein
La Dura Mine
Las Animas Vein
Victoria Tunnel
Arco Mine
Carriso Fault
Molinos Fault
Santa Ana Fault
San Gregorio Vein
San Nicolas
La Trinidad Vein
La Trinidad Mine
Colorado Mine
Madrid Fault
Calavasar Vein
Amarilla Vein
Amarilla Mine
La Prieta Vein
La Prieta
Navidad Madrid Vein
1000 E
2000 E
3000 E
4000 E
5000 E
6000 E
8000 N
7000 N
6000 N
5000 N
4000 N
3000 N
2000 N
1000 N
0 N

PLATE III



EXPLANATION

- Tr — Rhyolite Volcanics
- UNCONFORMITY
- Trd — Rhyolite dikes
- Td — Diabase dikes
- Tl — Quartz Latite dike
- Tqm — Quartz monzonite
- Granodiorite stock
- Tka — Topia Andesite (unaltered)
- Cm — Contact metamorphic zone (In Topia Andesite)
- Regional Propylitic Alteration zone (In Topia Andesite)

MID-TERTIARY

EARLY TO MID-TERTIARY

LATE CRETACEOUS(?) TO EARLY TERTIARY

- Contact
- Indefinite contact
- Fault
- Probable fault
- Shear zone
- Structural features (faults - joints) from aerial photographs
- Vein
- Inferred vein
- Shaft
- Mine portal
- Drainage

Geology by John Lemish, 1951-52

STRUCTURE AND ALTERATION MAP OF THE TOPIA MINING DISTRICT, DURANGO, MEXICO

DATA FROM AERIAL PHOTOS AND RECONNAISSANCE

DATA FROM GEOLOGIC MAP

0 250 500 1000 2000 Meters

0 500' 2000 ½ Mile 1 Mile

MAGNETIC DECLINATION

10°

TRUE NORTH

MAGNETIC NORTH