

THE GEOLOGY OF THE RANCHO LOS FILTROS  
AREA, CHIHUAHUA, MEXICO

A Thesis  
Presented to  
the Faculty of the Department of Geology  
East Carolina University

In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science in Geology

by

Jonathan G. Blount

May 1982

QF  
203  
C4  
B5x

THE GEOLOGY OF THE RANCHO  
LOS FILTROS AREA, CHIHUAHUA, MEXICO

by

Jonathan G. Blount

APPROVED BY:

DIRECTOR OF THESIS

Richard L. Manger  
Dr. Richard L. Manger

COMMITTEE MEMBER

Richard K. Spruill  
Dr. Richard K. Spruill

COMMITTEE MEMBER

Donald W. Neal  
Dr. Donald W. Neal

COMMITTEE MEMBER

Fred W. McDowell  
Dr. Fred W. McDowell  
University of Texas at Austin

CHAIRMAN OF THE DEPARTMENT OF GEOLOGY

C. Q. Brown  
Dr. C. Q. Brown

DEAN OF THE GRADUATE SCHOOL

Joseph B. Boyette  
Dr. Joseph G. Boyette





#### FRONTISPIECE

The view is toward the northwest portion of the field area from the northernmost Precambrian block (foreground). This block consists primarily of brownish metagranite that is cut by dark green dikes of amphibolite (A). A Precambrian postmetamorphic pegmatite (P) is visible in the left-central portion of the photograph. The limestone cliffs of the Sierra del Cuervo (SD) are visible in the background. A down-faulted block of these limestones (D) is shown on the right side of the photograph. At the base of the fault block, an intrusive mass of reddish-brown rhyolite is exposed (R). The small whitish area visible on the left-central edge of the photograph is one of the abandoned marble quarries (Q).

## ABSTRACT

Jonathan G. Blount. THE GEOLOGY OF THE LOS FILTROS AREA, SOUTHEASTERN SIERRA DEL CUERVO, CHIHUAHUA, MEXICO. (Under the direction of Dr. Richard L. Mauger) Department of Geology, May, 1982.

The study area is located on Rancho Los Filtros approximately 13.5 kilometers northwest of Aldama, Chihuahua, Mexico. In the study area massive cliff-forming Cretaceous limestones are intruded by sills of reddish altered rhyolite. Rhyolite is also found as a hypabyssal plug or small flow. Later intrusion of Paleocene granodiorite produced fine-to coarse-grained marble, grossularite and wollastonite near the limestone-granodiorite contact. These rocks overlie the Paleozoic Rara Formation.

The Rara Formation is divided into two units. One is a highly sheared turbidite sequence consisting of interbedded fine-grained sandstones and phyllitic shales. This unit also contains a meter-thick bed of strongly sheared arkosic, pebbly graywacke. The other unit consists of interbedded fine-grained sandstones and mudstones. These rocks are not so highly deformed as the turbidite unit. This unit forms an angular unconformity with the flat-lying Cretaceous rocks.

The Precambrian rocks in the area are restricted to several tectonic blocks which are in the turbidite sequence of the Rara Formation. These Precambrian rocks are primarily metagranites which are cut by abundant dikes of amphibolite. The metagranites exhibit moderately well-developed granoblastic textures, unmixing of alkali feldspar,

bulbous myrmekite, and rimming of plagioclase with albite. The amphibolites generally show well developed granoblastic textures. Relict igneous minerals and textures suggest that the amphibolites were metamorphosed under high load pressures and low differential stress conditions. Two K-Ar dates on hornblende (1025 and 1037 m.y.) from the amphibolites indicate that they are Grenvillian in age. These are the first Precambrian outcrops to be described from Chihuahua.

The Rara Formation and the Precambrian blocks are cut by numerous diabase dikes. The diabases plot well within the alkaline field of the alkali-silica diagram. Two varieties of lamprophyre (minettes and camptonite) are found as dikes and sills cutting the Precambrian, Paleozoic, and Cretaceous sections. Phlogopite from a camptonite dike was dated at 88.9 m.y. by K-Ar.

## ACKNOWLEDGMENTS

The work was done with support from National Science Foundation grant, EAR-7915240; R. L. Mauger, Principal Investigator.

I would like to thank Dr. Mauger for his selfless expenditure of time and energy in guiding the development of the thesis. I am also grateful to Dr. Richard K. Spruill and to Dr. Donald W. Neal who served as members of the thesis committee. Dr. Fred McDowell served as the outside advisor on the thesis committee and also performed the K-Ar age analyses. The Bureau of Geology and Mineral Technology and the Laboratory of Isotope Geochemistry at the University of Arizona at Tucson provided the facilities for mineral separation.

Dr. Scott Snyder and Virginia Waters are gratefully acknowledged for their freely-given assistance and encouragement. Fernando de la Fuente and the staff of the Consejo de Recursos Minerales are thanked for their hospitality during our stay in Chihuahua. The microprobe analyses were performed at Virginia Polytechnical and State University by Dr. Richard Mauger.

I deeply appreciate all that my parents have done to help me while I was in school and throughout my life. And lastly, I wish to thank my wife, Coleen, for her help and understanding, and most of all her love.

## TABLE OF CONTENTS

|                                                   |    |
|---------------------------------------------------|----|
| INTRODUCTION .....                                | 1  |
| <u>Location and Geologic Setting</u> .....        | 1  |
| <u>Previous Studies</u> .....                     | 1  |
| <u>Objectives</u> .....                           | 2  |
| <u>Methods</u> .....                              | 2  |
| LITHOLOGIC DESCRIPTION OF PRECAMBRIAN ROCKS ..... | 6  |
| <u>Introduction</u> .....                         | 6  |
| <u>Amphibolites</u> .....                         | 7  |
| <u>Metagabbro</u> .....                           | 7  |
| <u>Metabasalts</u> .....                          | 8  |
| <u>Porphyritic Metabasalts</u> .....              | 12 |
| <u>Metadiabases (Coronites)</u> .....             | 15 |
| <u>Metagranites</u> .....                         | 24 |
| <u>Gneisses</u> .....                             | 29 |
| <u>Hornblende Granite Gneiss</u> .....            | 29 |
| <u>Banded Biotite Gneiss</u> .....                | 29 |
| <u>Banded Hornblende Gneiss</u> .....             | 30 |
| <u>Plagioclase Pegmatites</u> .....               | 33 |
| <u>Postmetamorphic Pegmatite</u> .....            | 34 |
| LITHOLOGIC DESCRIPTION OF PHANEROZOIC ROCKS ..... | 37 |
| <u>Introduction</u> .....                         | 37 |
| <u>Lamprophyres</u> .....                         | 38 |
| <u>Diabase Dikes</u> .....                        | 48 |
| <u>Rhyolite</u> .....                             | 50 |
| <u>Granodiorite</u> .....                         | 53 |
| <u>Rara Formation</u> .....                       | 55 |
| <u>Cretaceous Carbonates</u> .....                | 56 |
| <u>Contact Metamorphic Rocks Skarr</u> .....      | 57 |
| GEOCHEMISTRY .....                                | 61 |
| <u>Amphibolites</u> .....                         | 61 |
| <u>Precambrian Felsic Rocks</u> .....             | 62 |
| <u>Rholite</u> .....                              | 63 |
| <u>Diabase Dikes</u> .....                        | 63 |

## TABLE OF CONTENTS (cont.)

|                        |    |
|------------------------|----|
| SUMMARY .....          | 65 |
| CONCLUSIONS .....      | 66 |
| REFERENCES CITED ..... | 68 |
| APPENDIX 1 .....       | 71 |
| APPENDIX 2 .....       | 72 |
| APPENDIX 3 .....       | 75 |
| APPENDIX 4 .....       | 76 |

## TABLES

|                                 |    |
|---------------------------------|----|
| 1. K-Ar Age Analyses Data ..... | 60 |
|---------------------------------|----|

## ILLUSTRATIONS

|                                                                                                          |    |
|----------------------------------------------------------------------------------------------------------|----|
| FRONTSPIECE: View of the Rancho Los Filtros Area .....                                                   | ii |
| 1. MAP: Location map of the study area in northern Mexico .....                                          | 3  |
| 2. MAP: Geologic map of the Rancho Los Filtros area, Chihuahua, Mexico .....                             | 5  |
| 3. DIAGRAM: Radiometric and relative ages of the major rock units .....                                  | 59 |
| 4. DIAGRAM: Location of the Ouachita Front in Texas and its possible location in Chihuahua, Mexico ..... | 67 |

## PLATES

|     |                                                                                                               |    |
|-----|---------------------------------------------------------------------------------------------------------------|----|
| 1.  | PHOTOMICROGRAPH: Photomicrograph of a metagabbro .....                                                        | 10 |
| 2.  | PHOTOMICROGRAPH: Photomicrograph of a poikilo-<br>blastic hornblende in a metagabbro .....                    | 10 |
| 3.  | PHOTOMICROGRAPH: Photomicrograph of a metabasalt .....                                                        | 14 |
| 4.  | PHOTOGRAPH: Photograph of a metamorphosed<br>prophyritic basalt .....                                         | 14 |
| 5.  | PHOTOMICROGRAPH: Photomicrograph of a<br>metamorphosed basalt .....                                           | 18 |
| 6.  | PHOTOMICROGRAPH: Photomicrograph of a<br>metadiabase .....                                                    | 18 |
| 7.  | PHOTOMICROGRAPH: Photomicrograph of hornblende<br>Coronas in metadiabase .....                                | 22 |
| 8.  | PHOTOMICROGRAPH: Photomicrograph of garnet<br>coronas in metadiabase .....                                    | 22 |
| 9.  | PHOTOMICROGRAPH: Photomicrograph of a metagranite .....                                                       | 28 |
| 10. | PHOTOMICROGRAPH: Photomicrograph of a bilbous<br>myrmekite .....                                              | 28 |
| 11. | PHOTOGRAPH: Photograph of a tectonic contact<br>between the Rara Formation and a Pre-<br>Cambrian block ..... | 32 |
| 12. | PHOTOGRAPH: Photograph of an outcrop of<br>biotite gneiss .....                                               | 32 |
| 13. | PHOTOGRAPH: Photograph of a plagioclase<br>pegmatite cutting basalt .....                                     | 36 |
| 14. | PHOTOGRAPH: Photograph of shale xenoliths in<br>a postmetamorphic pegmatite .....                             | 36 |
| 15. | PHOTOMICROGRAPH: Photomicrograph of panidio-<br>morphic pegmatite .....                                       | 36 |
| 16. | PHOTOMICROGRAPH: Photomicrograph of a spherulitic<br>minette .....                                            | 40 |
| 17. | PHOTOMICROGRAPH: Photomicrograph of intensely<br>altered minette .....                                        | 43 |
| 18. | PHOTOMICROGRAPH: Photomicrograph of panidio-<br>morphic camptonite .....                                      | 43 |
| 19. | PHOTOMICROGRAPH: Photomicrograph of an ocellus<br>in camptonite .....                                         | 47 |
| 20. | PHOTOMICROGRAPH: Photomicrograph of two ocelli<br>in camptonite .....                                         | 47 |
| 21. | PHOTOGRAPH: Photograph of a diabase dike cutting<br>the Rara Formation .....                                  | 49 |
| 22. | PHOTOMICROGRAPH: Photomicrograph of intergranular<br>diabase .....                                            | 52 |
| 23. | PHOTOGRAPH: Photograph of rhyolite sill intruding<br>Cretaceous limestone .....                               | 52 |
| 24. | PHOTOGRAPH: Photograph of outcrop of spheroidally<br>weathered boulders of granodiorite .....                 | 54 |
| 25. | PHOTOGRAPH: Photograph of bladed wollastonite in<br>a contact-metamorphic aureole .....                       | 58 |

## INTRODUCTION

### Location and Geologic Setting

The study area, 15 square kilometers within Rancho Los Filtros, is approximately 13.5 kilometers northwest of Aldama, Chihuahua, Mexico (Fig. 1). Los Filtros lies along the southeastern flank of the Sierra del Cuervo, which is the southern part of the Sierra Pena Blanca-del Cuervo block. This horst block range is situated along the boundary between the Chihuahua trough to the east and the Aldama platform to the west (Goodell, 1981).

The terrain of the Los Filtros area is rugged. Rolling hills of easily eroded sandstones and shales of the Rara Formation increase in size to the west. At the western edge of the study area, these sandstones and shales are capped by the Cretaceous units of the Sierra del Cuervo. A downfaulted block of these limestones is found along the north-central boundary of the study area (Fig. 2).

### Previous Studies

The Los Filtros area has not been studied in detail prior to the present investigation. The stratigraphy and structure of the Sierra del Cuervo and the Rara Formation have been described briefly in three other publications (Pearson and others, 1964; Tovar and Valencia, 1974; and Bridges, 1970).



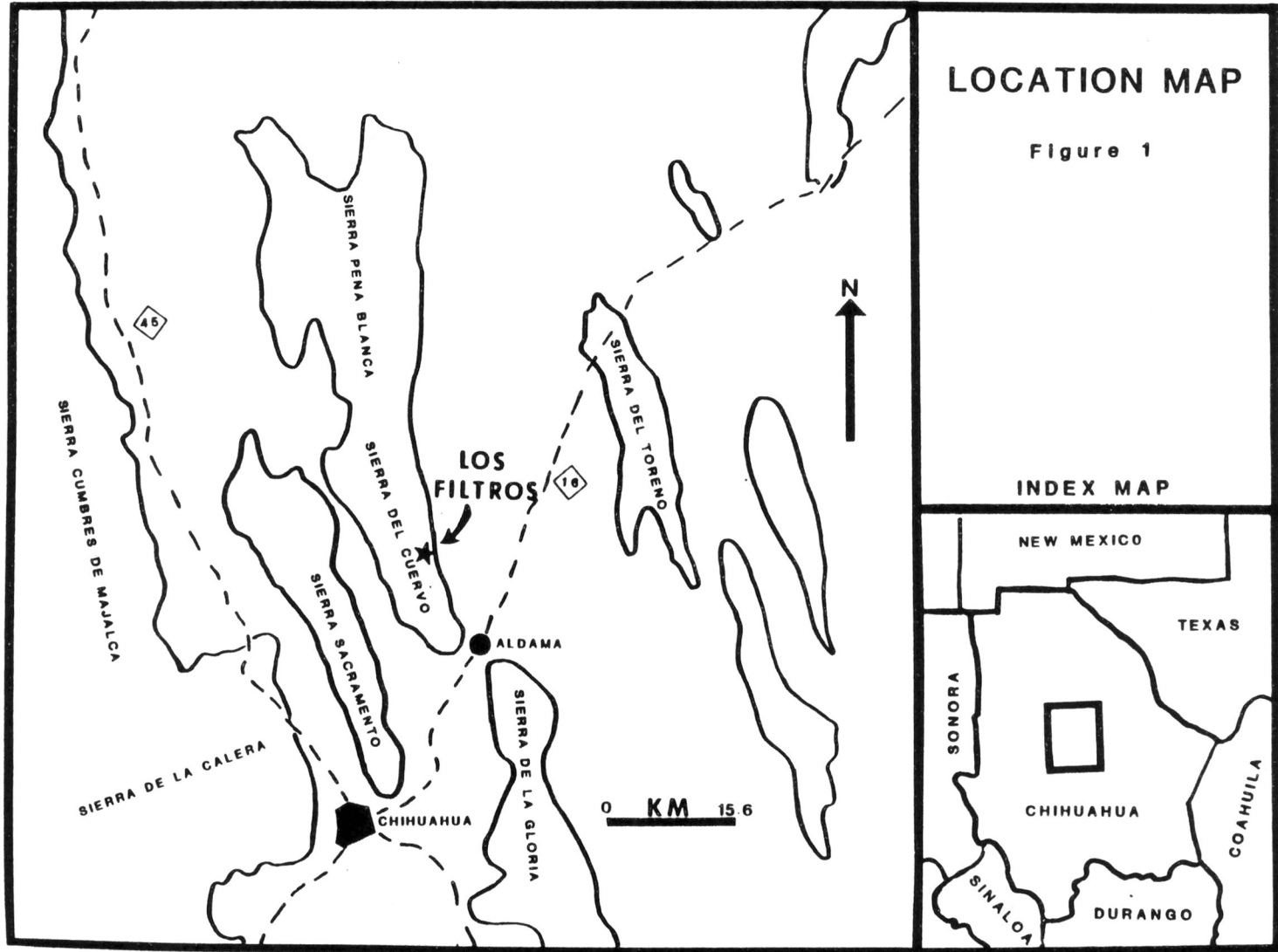
### Objectives

The objectives of this study are as follows:

- 1) To construct a geologic map;
- 2) To reconstruct the geologic history;
- 3) To subdivide the rock types on the bases of detailed petrography and geochemistry; and
- 4) To determine the parent lithologies of the metamorphosed rocks.

### Methods

Field work was undertaken during the summers of 1980 and 1981. Lithologies were mapped on the 1:50,000 Aldama (H13C57) and Sacramento (H13C56) DETENAL map sheets. Approximately 150 thin-sections were prepared and studied. Thirty-two samples were analysed chemically for major and selected trace elements. The mineralogy was determined by petrographic techniques and by electron microprobe.

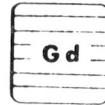


# LEGEND

ALLUVIUM



GRANODIORITE



RHYOLITE



SKARN



LAMPROPHYRE DIKE



RARA FORMATION

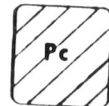


CRETACEOUS LIMESTONE



PRECAMBRIAN ROCKS

GRANITE AND AMPHIBOLITE



PEGMATITE



● ABANDONED MINE

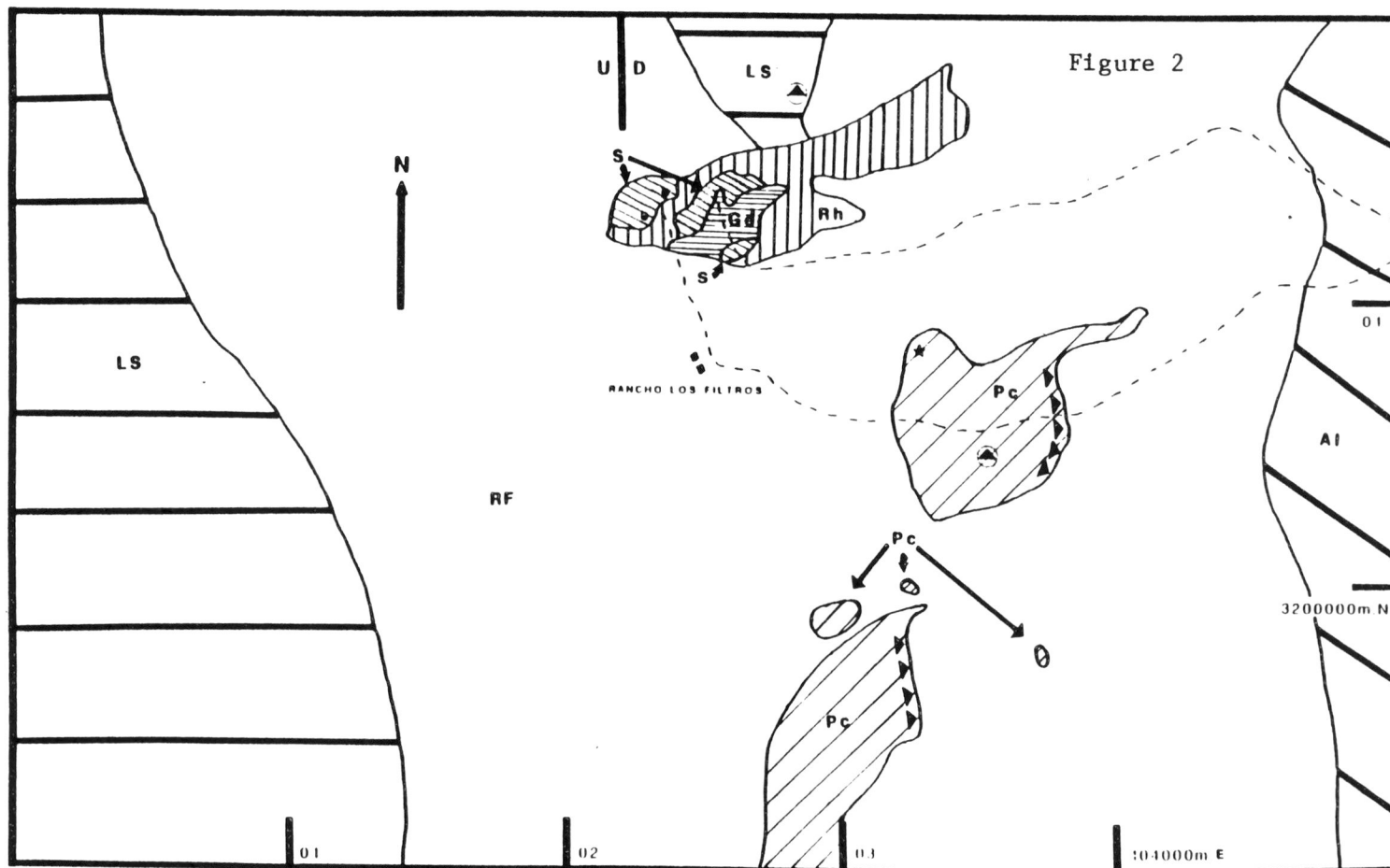
▼ ▼ INTENSE SHEARING

~ LITHIC BOUNDARY

- - - - DIRT ROAD

$\frac{U}{D}$  FAULT

# GEOLOGIC MAP OF THE RANCHO LOS FILTROS AREA CHIHUAHUA, MEXICO



## LITHOLOGIC DESCRIPTION OF PRECAMBRIAN ROCKS

### Introduction

The Precambrian rocks are restricted to several tectonic blocks that were emplaced into the Rara Formation. The Precambrian rocks consist of four units: 1) amphibolites; 2) metamorphosed granites; 3) gneisses; and 4) younger pegmatites. The amphibolites consist of metamorphosed gabbro, basalt, prophyritic basalt, and diabase dikes (coronites) that intruded the granites. The metagranites show great textural and mineralogic homogeneity. They are generally unfoliated and show moderately to well developed granoblastic textures.

## Amphibolites

### Metagabbro

This is the most abundant type of amphibolite in the Los Filtros area. In hand specimen the metagabbro is mesocratic with a color index of approximately thirty-three. It is mildly lineated and has a prominent spotted appearance. Shear fractures and veins of calcite, quartz, chlorite, and epidote are not uncommon.

The metagabbros consist primarily of plagioclase and hornblende (Appendix 1). Plagioclase grains average 1 mm in diameter and hornblende grains average 0.3 mm in diameter. Minor amounts of quartz, chlorite, calcite, epidote, sphene, magnetite, apatite, and garnet are also present.

The original feldspar was probably andesine, but some has undergone retrograde alteration to albite. The feldspar occurs in nearly monomineralic aggregates with moderately to well developed granoblastic textures (Plate 1). Relict laths of plagioclase are rare; they show bent or offset albite twins, deformation twins, and fractures. Sericitization is variable and locally intense.

The hornblende is pleochroic: X (pale yellow green); Y (olive green); Z (green). It generally occurs (with associated minor quartz) as equidimensional to elongate grains in irregularly shaped granoblastic aggregates (Plate 1). Rarely, the hornblende aggregates have coalesced to form poikiloblastic grains which contain abundant small quartz inclusions (Plate 2). The hornblende has a Fe/(Fe+Mg) ratio of 0.43.

Epidote and chlorite are ubiquitous minor constituents. Some epidote is probably of metamorphic origin and some is metasomatic.

Metamorphic epidote occurs as small columnar aggregates associated with plagioclase. The metasomatic epidote occurs in small veins and as granular patches, and it has a Fe/Fe+Al ratio of 0.33. It was also found to contain up to 1.3% SrO. Chlorite is often retrograde after hornblende, and it is also present in crosscutting veins.

The spotted appearance of the rock is produced by the segregation of hornblende from plagioclase. These separate patches of light and dark minerals have a dimensional-preferred orientation. This produces the mild lineation apparent in these rocks. The segregation of plagioclase and hornblende was produced when the clinopyroxene recrystallized as mimetic granoblastic aggregates of hornblende and quartz, and plagioclase recrystallized to granoblastic andesine (Plate 1).

Monomineralic plagioclase and hornblende aggregates were noted in texturally similar (Toecane type) amphibolites from western North Carolina (Wilcox and Poldervaart, 1958). These amphibolites have the same mildly lineated and spotted appearance as the Los Filtros metagabbros. According to Wilcox and Poldervaart, these amphibolites represent metamorphosed gabbros. Within a single large dike, they described a subophitic metagabbroic core which graded outward into a spotted amphibolite. The writer submits that the spotted amphibolites of Wilcox and Poldervaart and the Los Filtros metagabbros were both metamorphosed under high load pressures and low directed stresses.

### Metabasalts

These rocks consist of more than one generation of crosscutting, fine-grained, melanocratic dikes (Plate 13). The dikes are variable in thickness (generally less than 3 m) and they are indistinguishable in

## Explanation of Plate 1 and Plate 2

Plate 1. Photomicrograph of metagabbro, X46, analyzer at 45 degrees to polarizer. This shows the typical texture of the metagabbros with hornblende and andesine segregated into nearly monomineralic granoblastic aggregates. Note the straight "self boundaries" and triple points in both mineral aggregates. Interphase boundaries are more irregular.

Plate 2. Photomicrograph of metagabbro, X22, plane polarized light. Note the poikiloblastic hornblende with abundant inclusions of quartz.



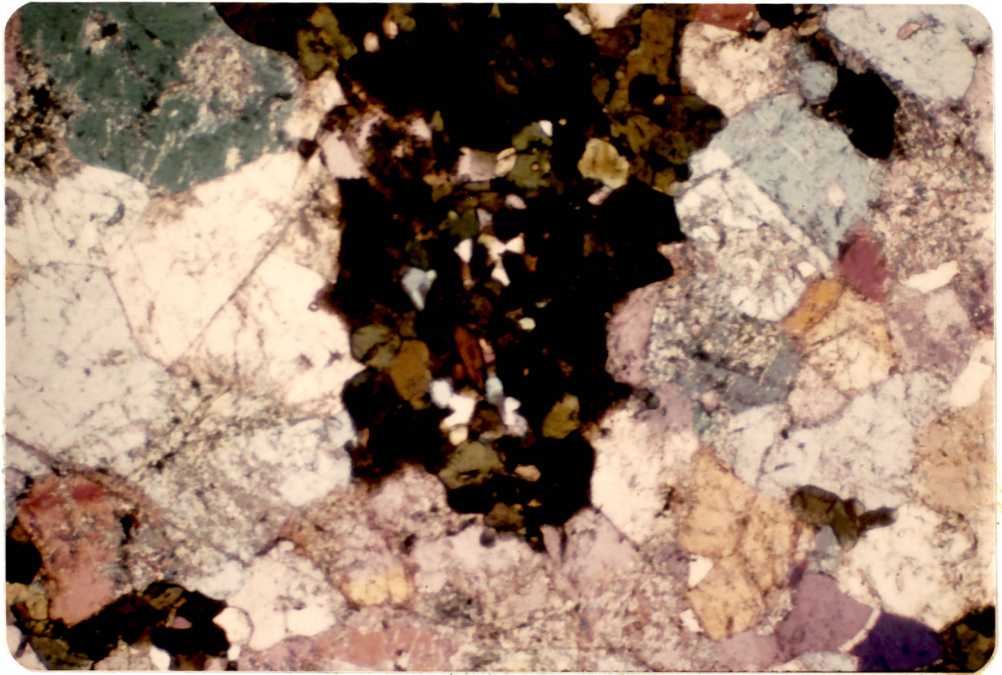


Plate 1

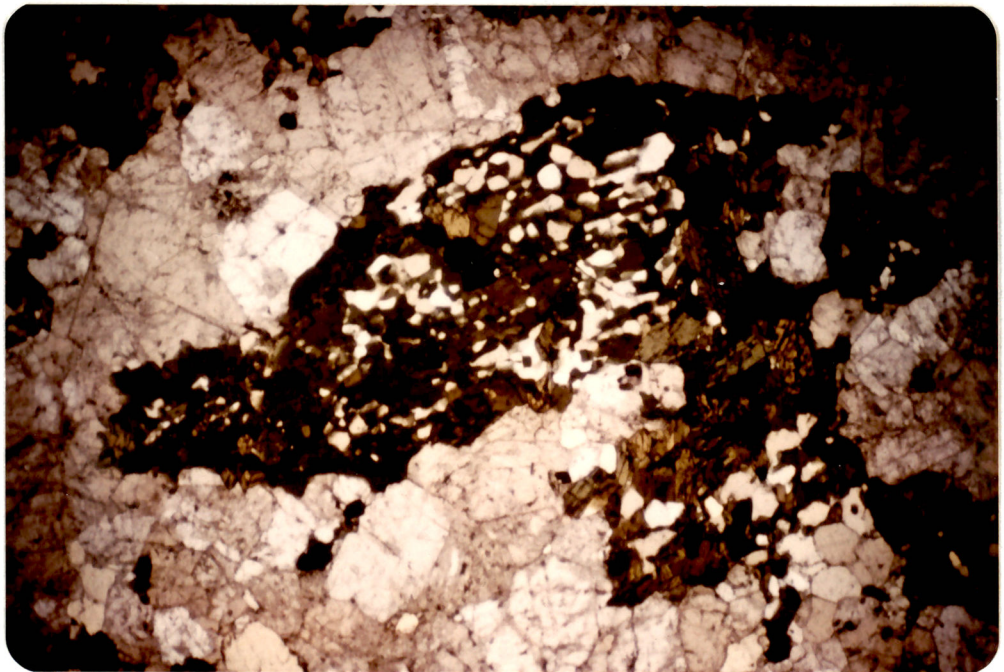


Plate 2

hand specimen from unmetamorphosed basalts. The average grain size is less than 0.25 mm, and the rocks consist primarily of granoblastic hornblende and plagioclase (Appendix 1). The remaining minerals are minor clinopyroxene, quartz, epidote, calcite, chlorite, sphene, sericite, apatite, biotite, magnetite, and garnet.

The hornblende grains are equant to slightly elongate; they may or may not show a rough lineation, and they display straight "self boundaries" (Spry 1969). The hornblende has the following pleochroic scheme: X (yellowish green); Y (brownish green); Z (green).

Plagioclase (andesine ?) grains are irregular and have slightly curved "self boundaries." The degree of sericitization varies from light to heavy. Complex twins are absent. Albite twins are rare and they are usually restricted to relict feldspar laths. This relationship indicates a probable igneous origin for the twinned grains.

Minor quartz is found as small grains associated with or included by aggregates of hornblende. Epidote occurs as intergranular coatings and more rarely as small columnar aggregates. Chlorite typically occurs as small crosscutting veinlets. Calcite is found as a vein mineral and as an alteration product associated with hornblende and clinopyroxene. The accessory minerals may vary in quantity locally but magnetite is usually the most abundant.

Textures range from nearly homogenous granoblastic intergrowths of hornblende and plagioclase to those which partially retain a subophitic texture despite recrystallization. In the latter textural variety small unpolygonized laths are present. In other varieties small plagioclase laths have been polygonized but their idiomorphic outlines are retained (Plate 3). Relict augite grains are also present (Plate 3). They are

very fine grained (approximately 0.1 mm), heavily fractured, clouded by opaques, and/or partially altered to calcite and chlorite. Rimming of these grains by metamorphic hornblende is not uncommon.

The relict textures in this unit were preserved by the same mimetic processes which affected the metagabbros.

### Porphyritic Metabasalts

These rocks are found as small dikes (less than 3 m in thickness), and they are the least abundant of the amphibolites. The phenocrysts are large, roughly aligned plagioclase laths set in a fine-grained melanocratic matrix. In outcrop this unit closely resembles a porphyritic basalt (Plate 4).

The mineralogy is typical of amphibolites derived from rocks of basaltic composition. Hornblende and plagioclase dominate the assemblage with epidote and sphene occurring as minor constituents. Quartz, chlorite, biotite, magnetite, and relict clinopyroxene are present as accessories (Appendix 1).

The hornblende typically occurs as small (0.3 mm, average diameter) equant to elongate grains (Plate 5). It is also found as large (up to 2.4 mm) grains in decussate aggregates. Both types have straight boundaries. The hornblende is pleochroic: X (pale yellow); Y (brownish green); Z (green) and it has a Fe/Fe+Mg ratio of 0.59.

The plagioclase ( $An_{28.2}$ ) may occur as small (0.4 mm average diameter) granoblastic to xenoblastic groundmass grains, or as large (up to 9 mm x 4 mm) relict phenocrysts (Plate 5). Some of the feldspar may have been altered to albite. Many of these laths display a crude subgrain texture. In both feldspar grain types sericitization is moderate to heavy and albite twins are not uncommon.

## Explanation of Plate 3 and Plate 4

Plate 3. Photomicrograph of metabasalt, X46, crossed nichols. The elongate granoblastic aggregates of plagioclase (see arrows) are recrystallized laths. A heavily fractured and clouded relict clinopyroxene grain (blue birefringence) is visible in the lower left corner. The groundmass consists of granoblastic hornblende and andesine.

Plate 4. Outcrop of metamorphosed porphyritic basalt containing relict plagioclase laths up to 1 cm in length.



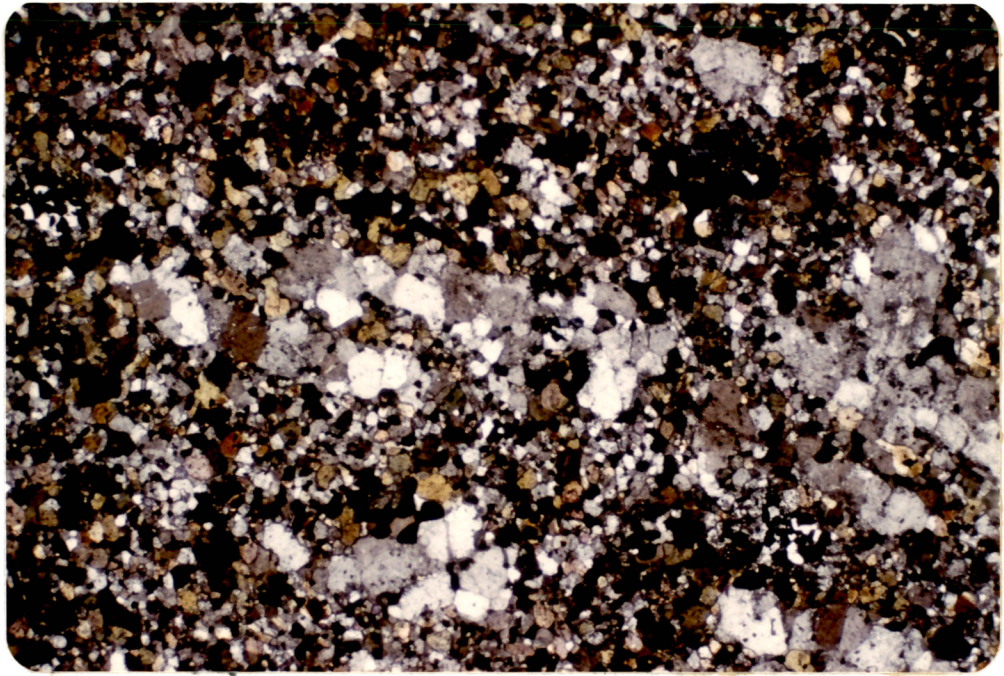


Plate 3



Plate 4

Epidote occurs in granular masses and as columnar aggregates. Its abundance is greater in areas adjacent to the relict feldspar laths and it is commonly associated with chlorite.

Sphene is an important minor constituent and the grains often contain a small central grain of magnetite. Relict augite is present as heavily clouded and fractured grains. One exceptionally large grain measured 1.5 mm in diameter and has a Fe/Fe+Mg ratio of 0.39.

Within this unit there is a definite concentration of columnar epidote in the vicinity of relict feldspar laths. Buddington (1939) noted that during metamorphism plagioclase may lose calcium ions without subsequent change in form. This would supply abundant calcium for the local development of epidote.

The decussate aggregates of hornblende possibly recrystallized from clinopyroxene phenocrysts. The presence of a relict clinopyroxene grain rimmed by a nearly monomineralic aggregate of hornblende supports this interpretation.

This unit is interpreted as a metamorphosed porphyritic basalt. Evidence includes the flow-lineated plagioclase laths, the actual and inferred clinopyroxene phenocrysts, and the fact that the unit was injected as small dikes.

#### Metadiabases (Coronites)

Coronites are rocks containing abundant coronas (Spry, 1969). The coronas consist of single or multiple layers of secondary minerals which form along the contact of two primary minerals of contrasting composition. Coronas are best developed in basic rocks, where they typically form along the contacts between plagioclase and iron-rich minerals

(clinopyroxene, olivine, iron oxides, etc.) Coronas can be subdivided into simple and complex forms (Buddington, 1939; Spry, 1969). Simple coronas usually have one layer, rarely more than two, and are developed by magmatic and deuteric processes. The mineralogy is simple, consisting of pyroxene, hornblende, and biotite (Spry, 1969). Complex coronas contain up to four layers and they have a more variable mineralogy including orthopyroxene, spinel, amphibole, and garnet. Of these, garnet is not formed during the low-pressure crystallization of a basaltic melt. The following hypotheses for the origin of complex coronas have been proposed:

- 1) Contact Metamorphic (Shand, 1945; Huang and Merritt, 1952)
- 2) Regional Metamorphic (Sederholm, 1916; Murthy, 1958; Wilcox and Poldervaart 1958)
- 3) Metasomatic (Reynolds and Fredrickson, 1962)
- 4) Retrograde cooling of deep-seated intrusives from igneous temperatures to local geotherm temperatures (Griffen and Heier, 1973).

The Los Filtros coronites are fine- to medium-grained melanocratic dike rocks. They are moderately fractured and abundantly veined by chlorite and lesser calcite. The mineral assemblage consists primarily of plagioclase, clinopyroxene, hornblende, and garnet. Minor amounts of ilmenite, calcite, chlorite, and accessory apatite, biotite, sericite, pyrite, chlorite, and chalcopyrite are also present.

The coronites contain relict diabasic features together with superimposed metamorphic features. The relict features include plagioclase laths and clouded clinopyroxene. The clouding was produced by the progressive replacement of clinopyroxene by minute granules of hornblende. The clinopyroxene grains are completely pseudomorphed by hornblende in

## Explanation of Plates 5 and 6

- Plate 5. Photomicrograph of metamorphosed basalt, X22, crossed nichols. The groundmass is composed of equant to elongate hornblende and granoblastic to xenoblastic plagioclase. The large grain in the center of the plate is a relict plagioclase lath. Sericitization of this lath is heavy.
- Plate 6. Photomicrograph of metadiabase (coronite), X46 crossed nichols. The original plagioclase is clouded. The original subophitic to ophitic clinopyroxene plates have undergone extensive hornblendization. The relatively unaltered core (blue birefringence) of the plate was analysed by microprobe and found to be diopsidic augite. The corona formed along the original contact of the plagioclase and clinopyroxene grains. It consists of an aggregate of discrete hornblende grains.





Plate 5

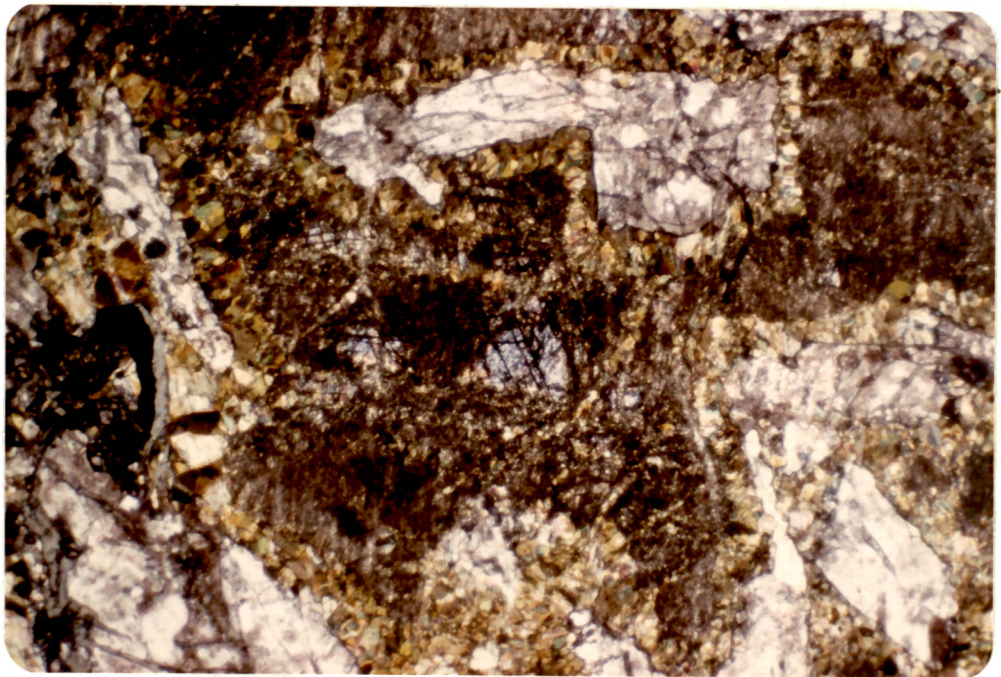


Plate 6

extreme cases. The original clinopyroxene plates were up to 4.5 mm x 3 mm in diameter and were diopsidic augite (Plate 6). Parallel striations found on many of the altered clinopyroxene grains may have been original parting fractures or exsolution lamellae (Plate 7). The relict plagioclase laths (up to 2 mm x 5 mm) are clouded by opaque and moderately to heavily seriticized. Carlsbad and albite twins are present but not common.

The metamorphic assemblage consists of hornblende, plagioclase and garnet. The plagioclase occurs as clear, mildly seriticized, untwinned and polygonized grains of albite. Hornblende forms coronas which enclose clouded clinopyroxene and grains of ilmenite. The hornblende is pleochroic: X (yellow green); Y (olive green); Z (dark green) and it has a Fe/Fe+Mg of 0.49. Garnet contains up to 4.8% MgO and it occurs as reaction rims which enclose ilmenite. Hornblende and garnet commonly show retrograde alteration to chlorite.

The coronas formed along grain contacts between clinopyroxene and plagioclase or between ilmenite and plagioclase. As the minerals reacted they were marginally replaced by coronas of hornblende and/or garnet. Two types of hornblende coronas developed around clinopyroxene or ilmenite grains (Plate 7). One is an aggregate of variable thickness made up of small (average 0.1 mm) radially oriented grains. The other is an elongate optically continuous rim less than 0.05 mm in diameter. Similar rims were described by Sutton and Watson (1951) for their least altered, stage-one metadolerites. The granular coronas form the innermost layer and they are often enveloped in turn by the optically continuous rims. This inner granular layer of hornblende is ubiquitous around clinopyroxene and it is also usually present around ilmenite grains.

The optically continuous rim is occasionally present around both minerals. Garnet coronas (Plate 8) consist of abundant discrete grains, and they occur exclusively as the outermost layer around ilmenite grains. Infrequently, either hornblende or garnet may form the only corona around ilmenite. The four varieties of coronas that developed in the Los Filtros area are listed below:

- 1) clinopyroxene -- hornblende -- plagioclase
- 2) ilmenite -- hornblende -- plagioclase
- 3) ilmenite -- garnet -- plagioclase
- 4) ilmenite -- hornblende -- garnet -- plagioclase

According to Murthy (1958) and to Wilcox and Poldervaart (1958), complex coronas and the clouding of primary minerals reflect low differential stress regional metamorphism under relatively dry conditions. The writer agrees that this is the most likely origin for the Los Filtros area coronites. Evidence for a regional metamorphic origin includes field relationships, textural relationships, and mineralogy.

The coronites are intimately associated with the other amphibolites but do not appear to crosscut them. Within the same dike a textural and mineralogic gradation can exist between a coronite and an amphibolite. Dikes or portions of dikes that were lightly sheared during metamorphism would probably not be subjected to extensive infiltration of water. This would allow development and retention of coronas in these relatively "dry" basaltic rocks. Amphibolites would form in dikes or in portions of dikes that were subjected to higher degrees of shearing and to subsequent increases in water content. Shearing stress and free water would destroy the delicate coronas. The pyroxene would recrystallize as

## Explanation of Plate 7 and Plate 8

Plate 7. Photomicrograph of metadiabase (coronite), X46, crossed nichols. Subophitic clinopyroxene plates were rimmed by two types of hornblende coronas. The inner rim consists of an aggregate of randomly oriented hornblende grains. The outer corona consists of a physically intermittent but optically continuous rim (at extinction position). The parallel striation on the altered clinopyroxene grain may be original parting fractures or exsolution lamellae (see arrows).

Plate 8. Photomicrograph of metadiabase (coronite), X46, plane polarized light. The garnet corona occurs as the outermost layer around ilmenite grains. The brownish-green inner corona is hornblende. Note the increased grain size of the individual garnets toward the plagioclase.





Plate 7

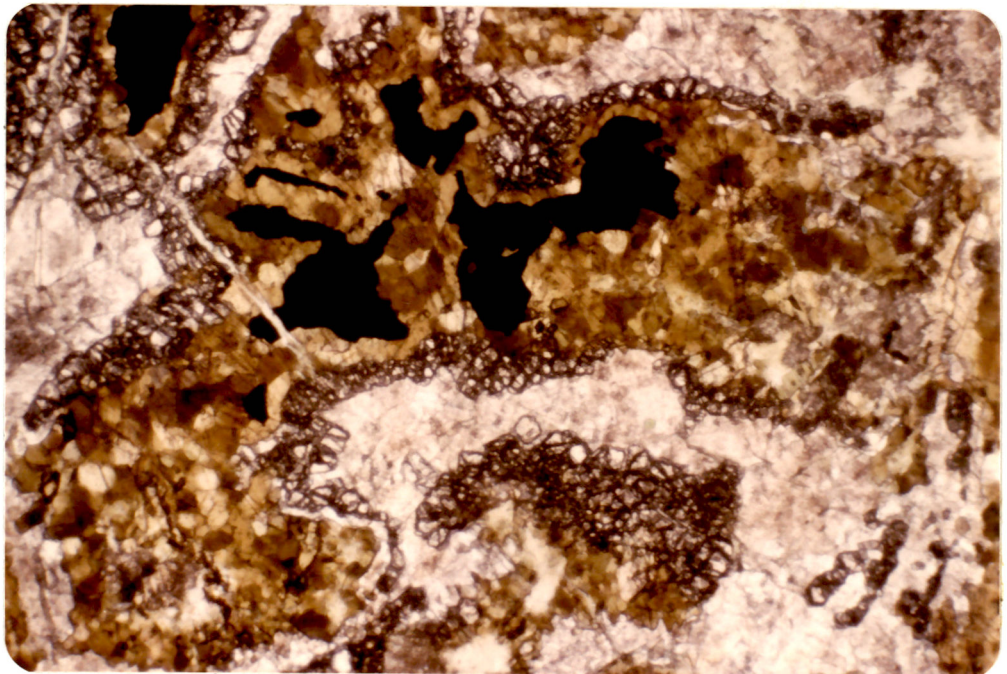


Plate 8

grandblastic hornblende, and the relict clouded plagioclase would recrystallize as clear granoblastic aggregates (Murthy, 1958; Wilcox and Poldervaart, 1958). This sequence of events has been documented in Adirondack metagabbroic dikes, where cores of corona-bearing metagabbros grade outward to garnet-rich amphibolites (Buddington, 1939, 1952).

### Metagranites

Fine-grained, brownish-orange to whitish-gray granites are the dominant Precambrian rock type in the Los Filtros area. They occur as dikes of variable size and as large masses of unknown intrusive affinity. The granites are the oldest rocks in the study area. They are cut by the amphibolites as well as by younger unmetamorphosed intrusives. Post-metamorphic shearing was ubiquitous.

The metagranites consist primarily of subequal amounts of plagioclase, microcline, and quartz (Appendix 1). Sphene, zircon, magnetite, sericite, and apatite are present in accessory amounts. Pyrite, biotite, chlorite, calcite, epidote, quartz, and hematite pseudomorphs of cubic pyrite are present as fracture fillings and vein minerals.

The granites have been extensively recrystallized resulting in a crystalloblastic texture. The rocks are dominantly fine grained with an average grain diameter of 0.8 mm. However, a quantitatively minor coarser phase averaging 2.2 mm in grain size was also noted. Microcline is typically granoblastic. Some premetamorphic plagioclase was probably oligoclase. It is now lightly to moderately sericitized and altered to xenoblastic to nearly granoblastic albite (Plate 9). Rarely, plagioclase is found as partially preserved idiomorphic laths. Quartz may occur as small rounded inclusions in the feldspars or as independent xenoblastic grains. Uncommonly, the quartz may show a dimensional-preferred grain form.

The microcline shows typical cross-hatch twinning (Plate 9). Plagioclase is dominantly untwinned, although twinning on the albite law

is not uncommon. Carlsbad, pericline and wedge-shaped deformation twins are present but are relatively rare. Albite twins are more common in those plagioclase grains which partially retain their idiomorphic form. The rare Carlsbad and pericline twins are generally restricted to these grains. This relationship indicates that many of the albite twins and possibly all of the complex twins may be igneous in origin (Turner, 1951). However, a possible metamorphic origin for the twins cannot be eliminated from consideration.

The feldspars in the granites have undergone significant unmixing during metamorphism resulting in the formation of several exsolution features: 1) coarse perthites and antiperthites; 2) bulbous myrmekite; and 3) albite rims. Perthites greatly predominate over antiperthites and are present in a many of the feldspar grains. Perthites take several forms: 1) patch; 2) interpenetrant; 3) flame; and 4) rounded blebs. Antiperthites are generally found as small patches of microcline in plagioclase. Bulbous myrmekite (Phillips and Carr, 1973; and Phillips, 1974) is common. It typically forms along plagioclase-microcline grain boundaries where it develops as a lobate oligoclase-quartz symplectite which marginally penetrates the microcline grain (Plate 10). Clear albite rims on plagioclase are abundant and they generally formed along the contacts between plagioclase and potassium feldspar grains (Plate 9). They are better developed in specimens showing granoblastic textures and are less developed in those rocks with abundant perthitic microcline. This observation is consistent with an exsolution origin for albite rims (Tuttle and Bowen, 1958).

The granites were subjected to a period of brittle deformation subsequent to the amphibolite facies metamorphism. This event was



probably related to their emplacement as tectonic blocks into the Rara Formation. This movement produced pervasive shearing, fracturing, and minor quartz, chlorite and epidote veining. This event may have caused the retrograde alteration of oligoclase to albite. The intensity of the deformation varies from ubiquitous small fractures to zones of intense shearing along the periphery of the crystalline blocks. Rocks in the highly sheared zones have a cherty, massive appearance in hand specimen. In thin section they resemble cataclasites (Higgins, 1971). These rocks have been partially silicified by the introduction of microcrystalline quartz. This may have occurred during or subsequent to the shearing episode.

One of the intensely sheared zones is found along the eastern boundary of the southwestern-most Precambrian exposure (Fig. 2). Here a resistant silicified dike-like structure forms a linear topographic feature (Plate 11). This zone of highly sheared and silicified rock marks a tectonic contact between the Rara Formation and the crystalline block.

## Explanation of Plate 9 and Plate 10

Plate 9. Photomicrograph showing typical section of metagranite, X46, crossed nichols. Microcline demonstrates straight "self boundaries" and well developed tartar twinning. Plagioclase is moderately sericitized and forms curved to irregular boundaries with microcline. Clear albite rims occur around sericitized plagioclase grains (see arrows) that are bounded by microcline.

Plate 10. Photomicrograph of bulbous myrmekite, X112, analyzer at 45 degrees to polarizer, gypsum plate in. The myrmekite consists of plagioclase (maroon) and vermicular quartz (light blue). It is shown penetrating a microcline grain (light yellow).

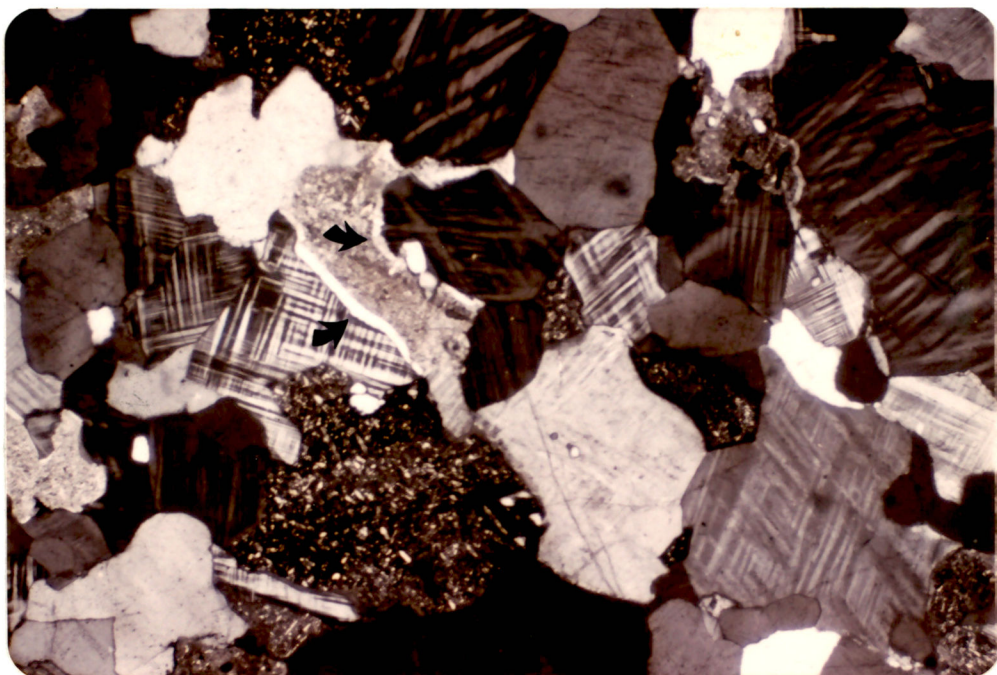


Plate 9

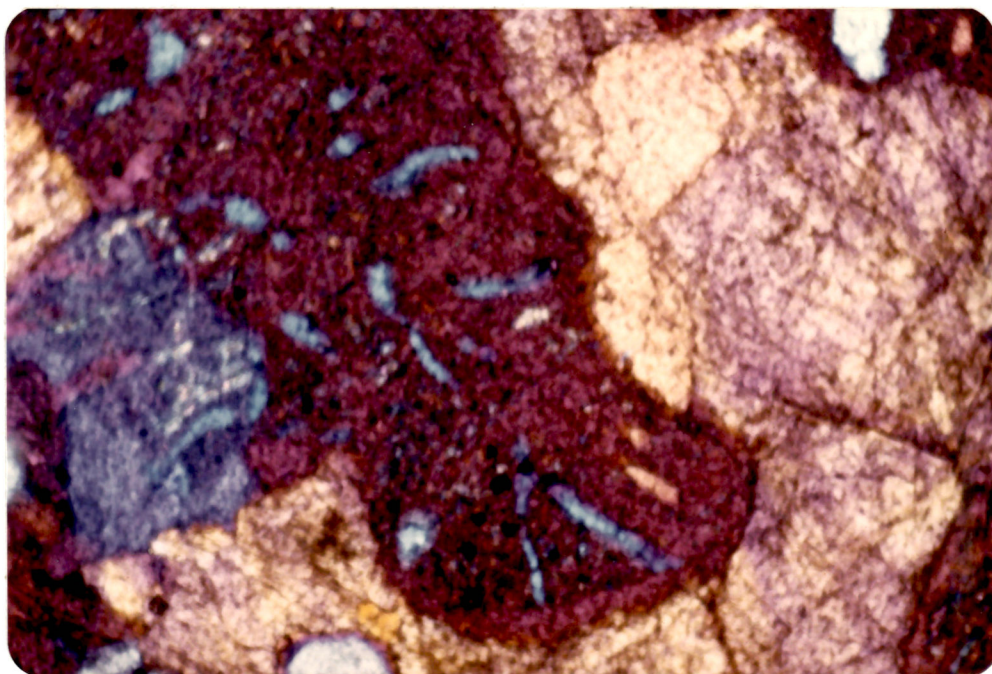


Plate 10

## Gneisses

Three small outcrops of texturally distinct gneisses were found in the study area. A hornblende granite gneiss was found as a small dike less than 1.5 m in thickness. This dike cuts the recrystallized granites and has a north-south strike. The remaining outcrops are a moderately folded, banded biotite gneiss (Plate 12) and a banded hornblende gneiss. Due to poor exposure the mode of emplacement for these two gneisses was indeterminant.

The gneisses range from granitic to intermediate in composition (Appendix 1). They exhibit many textural and mineralogical similarities to the metagranites. These include granoblastic to near-granoblastic textures and similarities in feldspar compositions, twinning relationships, exsolution features, and alteration.

### Hornblende Granite Gneiss

This unit is fine grained (0.6 mm average) and its gneissic character is derived by lattice- and dimensional-preferred hornblende prisms. Minor biotite is present along post-metamorphic microfractures and may partially replace hornblende as "cross-micas" (Spry, 1969).

### Banded Biotite Gneiss

This fine-grained unit (0.75 mm average diameter) is chemically similar to a granodiorite (Appendix 2). This is reflected by the plagioclase to microcline ratio of 3:1. Biotite is the primary mafic mineral and it imparts the foliation.

### Banded Hornblende Gneiss

This gneiss is intermediate in composition and has an average grain size of 1 mm. The dominant feldspar is andesine with microcline present in minor amounts. The primary mafic minerals are hornblende and epidote. The hornblende shows a dimensional-preferred orientation and it is occasionally partially altered to chlorite. Epidote occurs as small grains associated with chlorite and as small veinlets which crosscut the foliation of the rock at low angles. This suggests that some of the epidote grains may be of metasomatic origin.

## Explanation of Plate 11 and Plate 12

Plate 11. This ridge (see arrows) marks a tectonic contact between the Rara Formation (RF) and the southern-most Precambrian block (Pc). This resistant ridge consists of intensely sheared and silicified metagranites. The limestone cliffs of the Sierra de Cuervo are visible in the background.

Plate 12. This is an outcrop of folded biotite gneiss. The dark bands are relatively enriched in biotite and plagioclase. The lighter areas are more enriched in quartz and microcline. The coin in the center of the photograph is 2.7 centimeters in diameter.





Plate 11

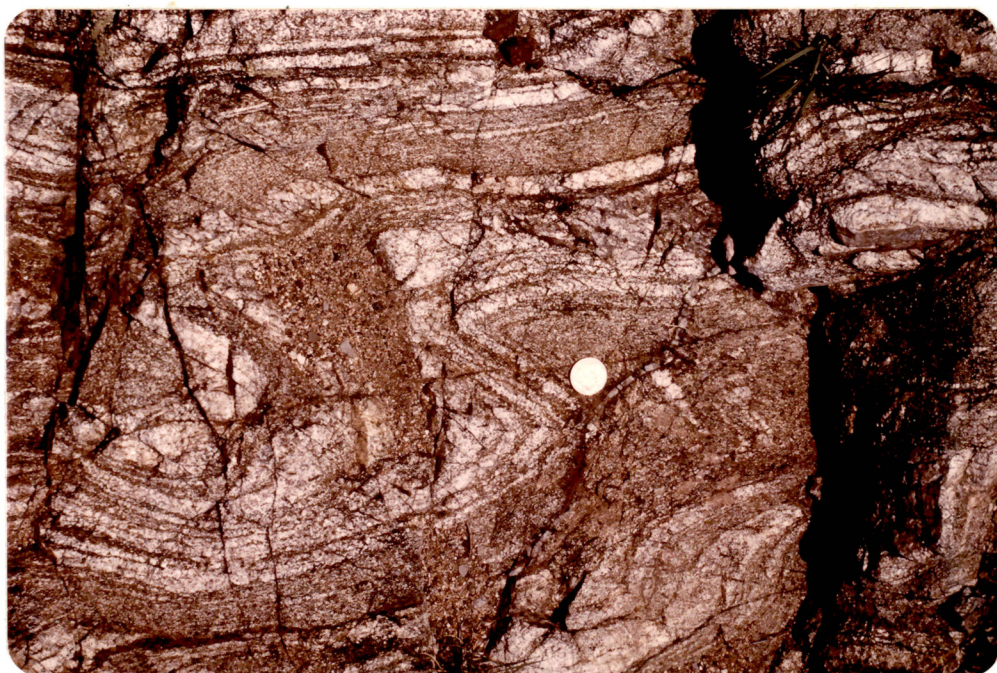


Plate 12



### Plagioclase Pegmatites

The plagioclase pegmatites are the least abundant unit in the crystalline blocks. They occur as small leucocratic dikes that range from 5 cm to approximately 2 m in thickness. The pegmatites are white to light pink and contain light-green patches of chlorite. They cut the metagranites and the amphibolites (Plate 13.)

The grain size is variable but averages 4 mm in diameter. The mineral assemblage consists primarily of plagioclase (andesine?) and quartz. Calcite and chlorite are present in variable amounts. Euhedral zircons (up to 0.3 mm in diameter), sphene, microcline, apatite, and sericite are present as accessories. Plagioclase grain boundaries may be highly irregular, sutured, or rarely granoblastic. Plagioclase with antiperthitic microcline is present but uncommon. Bent or offset albite twins are abundant. The quartz has sutured boundaries, and it shows undulatory extinction.

Generally the pegmatites have more poorly developed equilibrium textures than the amphibolites or metagranites. This suggests that they may have been formed by less intense late-stage metamorphic processes. It is also possible that they represent original igneous pegmatites which were intruded before the metamorphism. Their general lack of granoblastic textures may be the result of their dominantly quartz and plagioclase composition.

### Postmetamorphic Pegmatite

This pegmatite consists of pink orthoclase, quartz, and lesser amounts of muscovite. No evidence for metamorphism is apparent. A K-Ar age of 948 m.y. was determined for the muscovite (Table 1). This age gives the date that the pegmatite was intruded into the previously metamorphosed Precambrian rocks. Two large shale xenoliths are included in the pegmatite (Plate 14). Possible sources of these xenoliths include a presently unrecognized portion of the Rara Formation that is Precambrian in age or some extraneous Precambrian shaly unit.

## Explanation of Plate 13 and Plate 14

Plate 13. Plagioclase pegmatite cutting a dike of metabasalt. The pegmatite consists primarily of plagioclase, quartz, chlorite and calcite. The metabasalt is dominantly very fine-grained (0.1 mm average diameter) hornblende and andesine.

Plate 14. Precambrian postmetamorphic pegmatite. Two shale xenoliths (x) are visible.



Plate 13



Plate 14

## LITHOLOGIC DESCRIPTIONS OF PHANEROZOIC ROCKS

Introduction

The Phanerozoic units include rocks of igneous, contact metamorphic, and sedimentary origin. The igneous lithologies include Permian to Early Cretaceous diabases, Upper Cretaceous to Paleocene rhyolite, granodiorite, and lamprophyres. The sedimentary rocks include the Paleozoic Rara formation and the Cretaceous Las Vigas, Cuchillo, and Aurora Formations. Contact metamorphic rocks were produced by the intrusion of the granodiorite into the Cretaceous limestone.

### Lamprophyres

Minettes and camptonites occur in the study area. Several dikes and a sill of minette, all less than 3 meters in thickness, intrude the Paleozoic and Cretaceous sections (Fig. 3). The minettes are medium- to purplish-gray, variably altered, fine-grained porphyritic rocks. Weathered surfaces may be pitted by the preferential leaching of ferromagnesian minerals. A single camptonite dike less than 2 meters in thickness intrudes the Precambrian terrane. This dike is fine grained and dark gray with variable amounts of phlogopite phenocrysts and leucocratic ocelli.

The textures of the minettes are highly variable, ranging from panidiomorphic to spherulitic (Plates 15 and 16). The groundmass consists of potassium feldspar and up to 20 percent of plagioclase. The plagioclase may occur as small laths, subhedral grains, or as curved sheaf-like aggregates typical of a quench texture. The groundmass also contains abundant titanomagnetite and calcite. Chlorite is generally present in minor amounts, but it is very abundant in the interstitial areas of the spherulitic minette. Quartz, sericite, apatite, pyrite, sphene, and zeolites are ubiquitous accessories.

The minettes have 20 to 30 percent phenocrysts. Phlogopite averaging 0.8 mm in diameter comprises 5 to 20 percent of the rock. Subordinate euhedral clinopyroxene (diopside) averaging 1 mm in diameter occurs as individual grains or as clusters (Plate 15).

The minettes have been variably altered. In some the phenocrysts and the groundmass are relatively fresh. Others are intensely altered (Plate 17). Clinopyroxene phenocrysts are often altered to calcite

## Explanation of Plate 15 and Plate 16

Plate 15. Photomicrograph of panidiomorphic minette, X22, analyzer at 45 degrees to polarizer. The groundmass consists of potassium feldspar and minor plagioclase. The cluster of grains is diopside and minor greenish-brown phlogopite (center).

Plate 16. Photomicrograph of spherulitic minette, X46, gypsum plate in. Small, dark elongate crystals in the spherulite are biotite. Dark semicircle along the lower right boundary of the spherulite is interstitial chlorite.



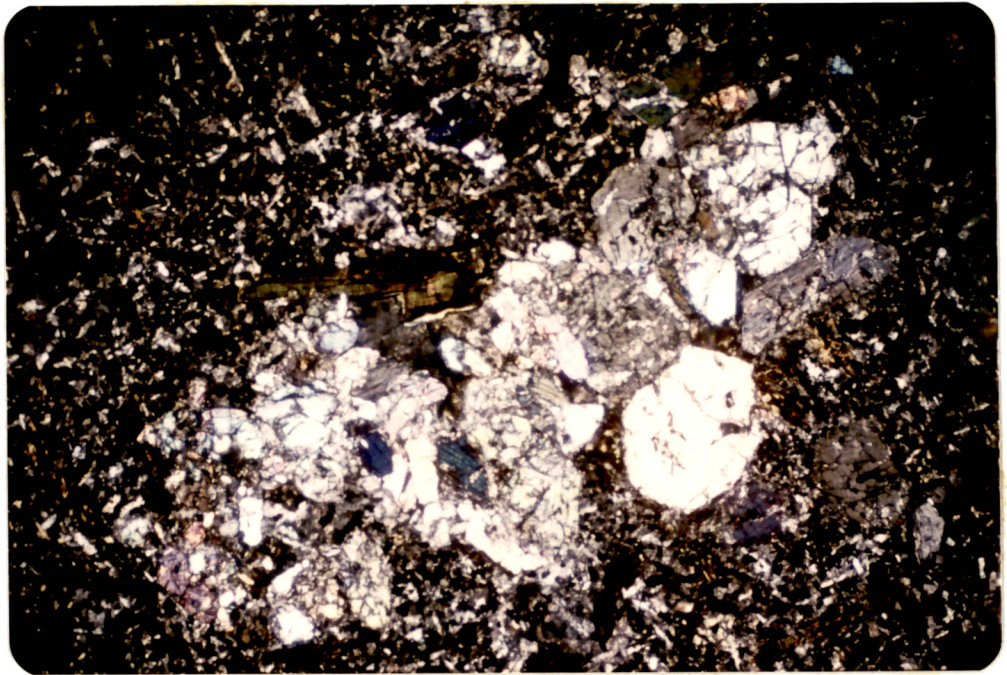


Plate 15

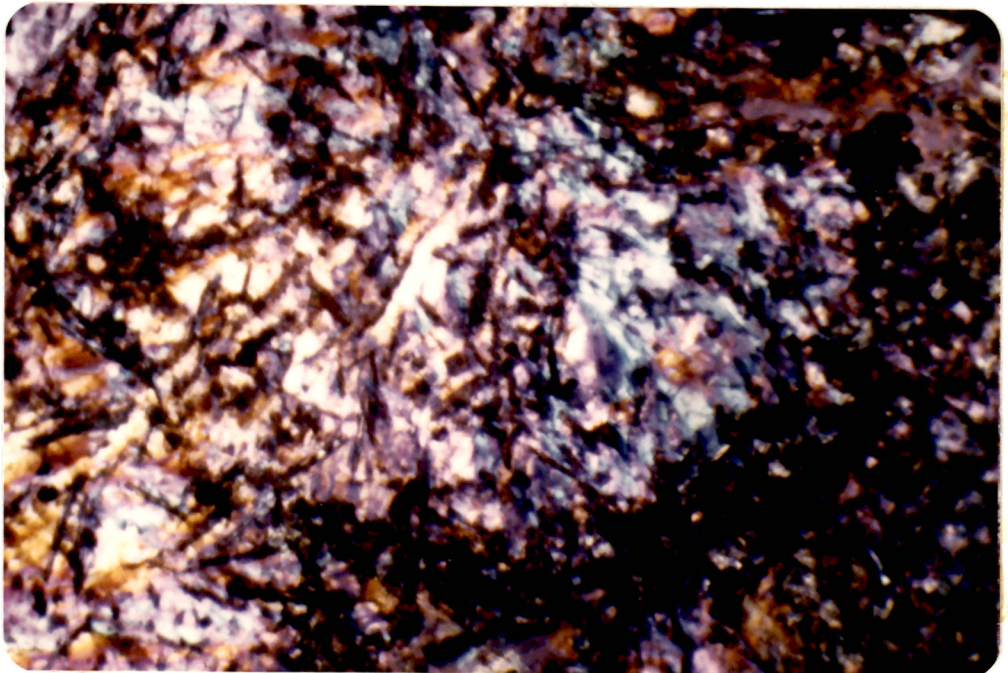


Plate 16

and/or chlorite, but original idiomorphic outlines are retained. Phlogopite may be fresh or altered to chlorite and/or to streaks of hematite.

The camptonite has a panidiomorphic texture with two generations of ferromagnesian minerals (Plate 18) and abundant leucocratic ocelli. The mineral assemblage consists of plagioclase, hornblende, clinopyroxene, phlogopite, titanomagnetite, calcite, minor alkali feldspar, and accessory pyrite and apatite. The plagioclase is andesine to labradorite; it is partially replaced by calcite. This feldspar occurs as euhedral to subhedral laths that average less than 0.15 mm in length. Hornblende is abundant in the groundmass and in the ocelli, and it has a Fe/Fe+Mg ratio of 0.32. Simple twinning is not uncommon, and the hornblende is pleochroic as follows: X (straw yellow); Y (greenish brown); Z (dark brown). The interiors are greenish brown and the rims are dark brown. The rims are nearly opaque in extreme cases (Plate 19). This color zonation probably results from progressive iron enrichment during growth (Cooper, 1978 p. 147).

Colorless to pale-green augite to diopsidic augite is common in the groundmass and as phenocrysts, but it does not occur in the ocelli. The clinopyroxene may be equant or prismatic. The phenocrysts average 1 mm in diameter and the groundmass grains average less than 0.1 mm (Plate 18). The phenocrysts commonly demonstrate concentric zonation and more rarely hour-glass structure. A few phenocrysts show a green pleochroic core mantled by a colorless to very pale-green rim. This greenish core may contain up to 1 percent  $\text{Na}_2\text{O}$ .

Phlogopite is common in the groundmass. Rare phlogopite phenocrysts range up to 1 cm in diameter. They are pleochroic from light to dark brown and they invariably have thin, dark reddish-brown rim (Plate 18).

## Explanation of Plate 17 and Plate 18

Plate 17. Photomicrograph of intensely altered minette, X22, plane polarized light. The phenocryst was probably clinopyroxene but is now completely altered to chlorite and calcite. The white grain on the left of the altered phenocrysts is a euhedral apatite crystal (see arrow). The groundmass of this minette has been altered to a mass of calcite, chlorite, and minor zeolites.

Plate 18. Photomicrograph of panidiomorphic camptonite, X46 crossed nichols. The groundmass consists of very fine-grained hornblende, phlogopite clinopyroxene, plagioclase, titanomagnetite and interstitial calcite. The phenocrysts are diopsidic augite and phlogopite. Note the rounded shape and the dark rim of the phlogopite.



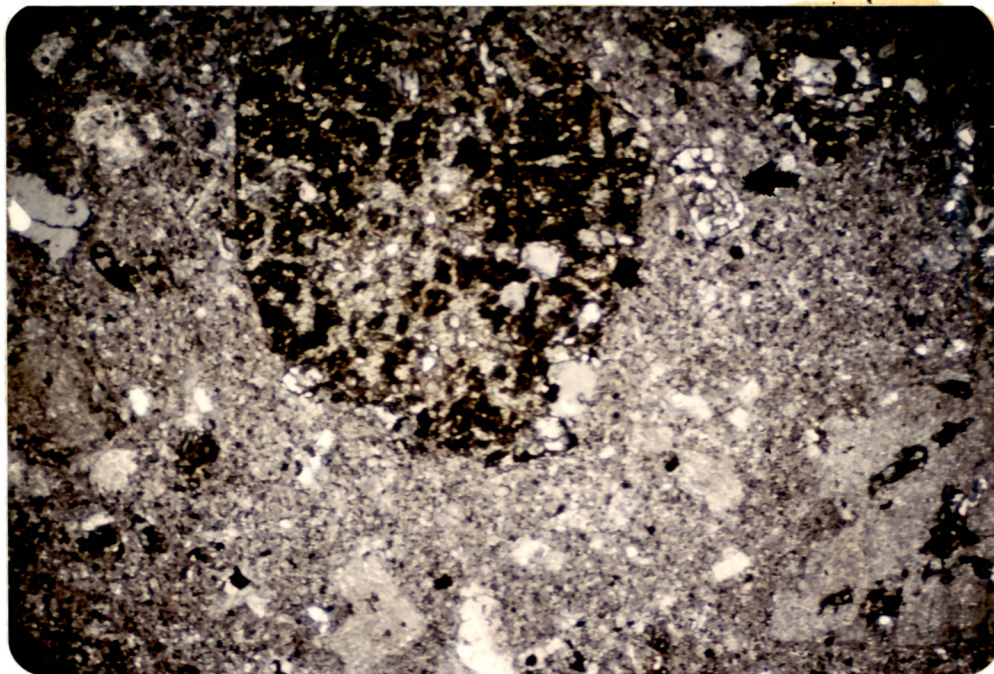


Plate 17

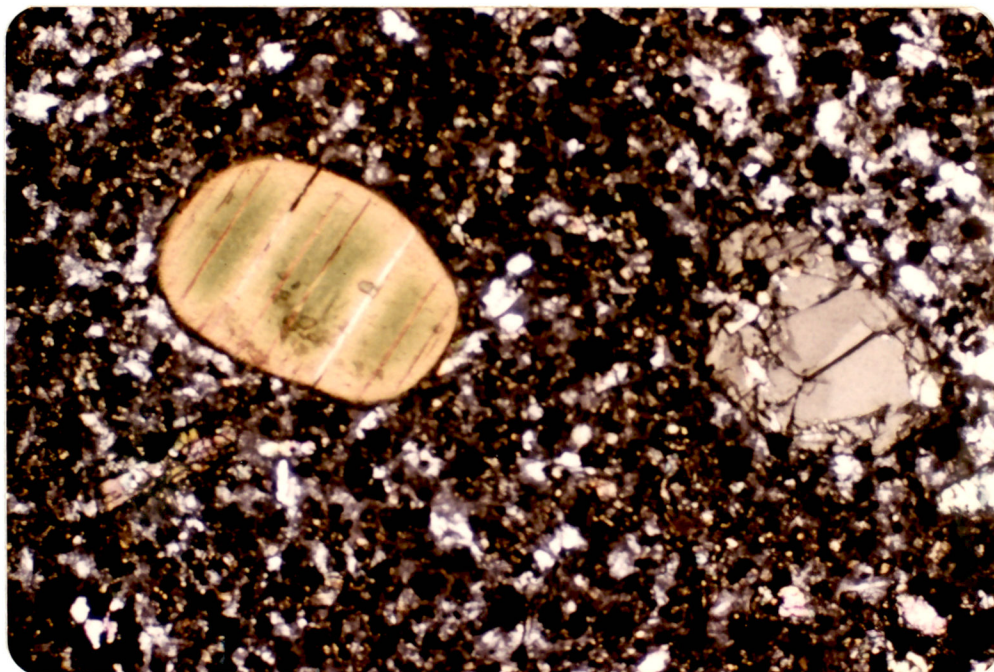


Plate 18

These dark rims represents zones that are enriched in iron. The Fe/Fe+Mg ratios for the interiors of the phlogopite phenocrysts average 0.18, the ratios at the rims average 0.30.

Calcite is abundant as interstitial microcrystalline patches and as an alteration product of the groundmass silicate assemblage. Replacement of silicate phenocrysts by calcite is minor. Calcite is also a major constituent of the ocelli. Alkali feldspar is present as a minor phase in the groundmass and possibly in the ocelli. Opaques in the camptonite consist of abundant titanomagnetite and greatly subordinate pyrite.

The ocelli are spherical to ellipsoidal in cross-section and range up to 6 mm in diameter. The minerals within the ocelli are similar to those in the rest of the camptonite. Abundant elongate hornblende crystals are the most striking features of the ocelli. The crystals range up to 1.5 mm in length and they often radiate inward from the ocelli-groundmass interface (Plate 19). Lesser amounts of radially oriented andesine ( $An_{45}$ ) laths are present. These average 0.5 mm in length and they are usually partially replaced by calcite. Calcite also occurs as brownish-gray microcrystalline masses and more rarely as aggregates of small clear crystals. Associated with the microcrystalline calcite are nearly isotropic patches that may be analcime. Small amounts of titanomagnetite and pyrite are commonly found in the ocelli.

Invariably one side of an ocellus has a much higher concentration of hornblende and feldspar than the other (Plate 19). This assymetrical distribution occurs along the same sides in all ocelli (Plate 20). This feature may be a geopetal structure. Unfortunately, this possibility cannot be confirmed because the original orientation of the samples with respect to up or down is not known.

Camptonite is thought to be produced by the crystallization of unusually hydrous alkali-enriched basaltic magma that is derived from partial melting of undepleted mantle (Rock, 1977; McHone and Corneille, 1981). The major and trace elements of the Los Filtros camptonite are compatible with this interpretation (Appendix 2). Of particular significance are the high  $K_2O$ ,  $Na_2O$ , Sr and Ba contents relative to the low silica content.

The ocelli in the Los Filtros camptonite are believed to be products of liquid immiscibility, as recognized in similar rocks from other areas (Ferguson and Currie, 1971; Philpotts, 1976; and Rock, 1977). According to Rock (1977), the hydrous nature of a camptonite melt promotes the development of an unusually high water-vapor pressure. Rock proposed that this high  $PH_2O$  expands the range of temperatures under which silicate-silicate or silicate-carbonate immiscibility can occur. This process might promote the development of immiscible droplets (ocelli) in camptonite melts. The Los Filtros minettes have an intermediate silica content and are enriched in  $Na_2O$ ,  $K_2O$ , Ba and Sr (Table 2). Rock (1977) states that minettes are formed by the hybridization of granites and basaltic magmas in an active orogenic zone. More recent work by Bachinski and Scott (1979) indicates that minettes may be derived by very small degrees of partial melting of mantle material that has been previously metasomatically enriched in the rare-earth and incompatible elements.

Some of the minettes cut the Cretaceous limestone indicating a maximum age of approximately 100 million years. The Camptonite was dated at 89 m.y (Table 1.) The K-Ar and stratigraphic ages indicate that the minettes and camptonite could be coeval.

## Explanation of Plate 19 and Plate 20

Plate 19. Photomicrograph of ocellus in camptonite, X22, plane polarized light. The upper right side of the ocellus contains abundant crystals of hornblende and plagioclase which often radiate inward from the ocellus-groundmass interface. The gray massive material which forms the bulk of the ocellus is microcrystalline calcite. Note the nearly opaque rims around hornblende crystals (see arrows.) The two phenocrysts visible outside the ocellus are diopsidic augite.

Plate 20. Photomicrograph of two ocelli in the camptonite, X22 plane polarized light. Note the concentration of hornblende and feldspar crystals along the same side in both ocelli. This may represent a geopetal structure.



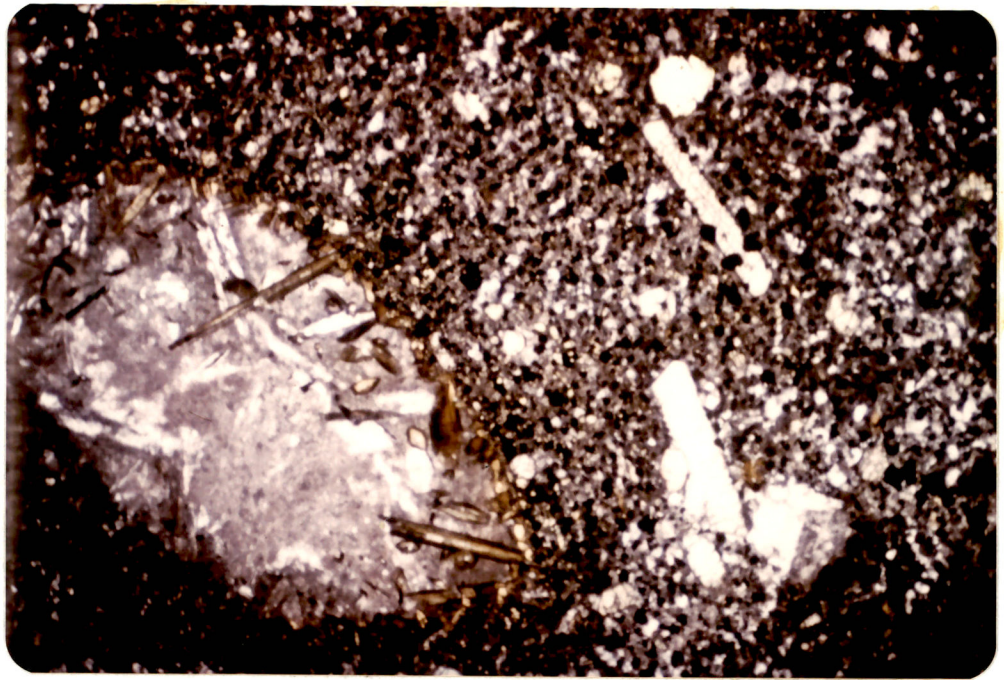


Plate 19

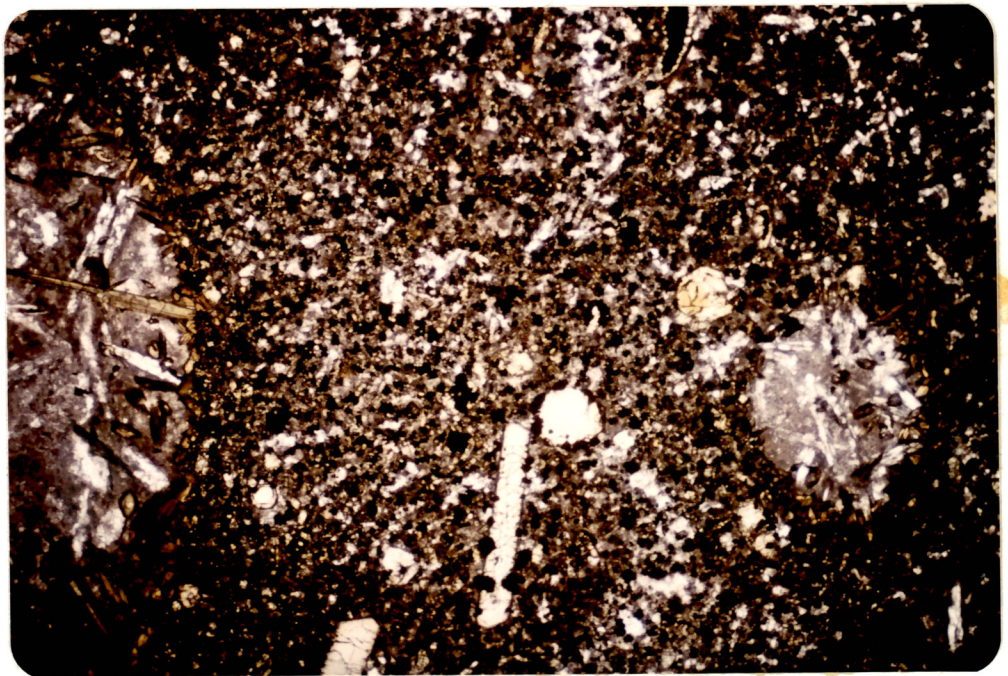


Plate 20

### Diabase Dikes

Five fine-grained, melanocratic diabase dikes were sampled in the study area. Four intruded the Precambrian terrane and one intrudes the Rara Formation (Plate 21). The dikes in the Precambrian terrane may or may not be restricted to these tectonic blocks.

The diabases have variable textures. A glomeroporphyritic variety with plagioclase phenocrysts up to 4.2 x 2.7 mm in diameter, and varieties with intergranular textures were noted (Plate 22). The rocks contain abundant plagioclase, augite, chlorite, and minor amounts of magnetite, biotite, calcite, apatite, and sericite. Plagioclase is altered to albite in the intergranular varieties. Phenocrysts in the glomeroporphyritic variety range up to bytownite. The clinopyroxene is augite to diopsodic augite and it is sometimes rimmed by deuteritic biotite. Chlorite is abundant and occurs as an alteration product of clinopyroxene and as interstitial material. Minor calcite is present as an alteration product of feldspar and pyroxene. Sericitization of feldspar is ubiquitous and it is generally more intense for the larger phenocrysts. In some cases entire phenocrysts are altered to single, optically continuous white mica crystals.



Plate 21. Diabase dike cutting the thinly-bedded turbidite sequence of the Rara Formation. This dike is approximately 2 m thick.



### Rhyolite

Rhyolite occurs as reddish, altered sills in the Cretaceous limestones of the Sierra del Cuervo (Plate 23). Rhyolite is also found as an intrusive mass which cuts the Rara Formation and Cretaceous limestone (Fig. 3). This intrusive mass has prominent vertical flow banding. The rhyolites may be massive or brecciated; they contain abundant limestone xenoliths which range in size from pebbles to boulders.

In thin-section the matrix exhibits a microgranophyric intergrowth of poikilitic quartz and relatively fresh orthoclase. Hematite altered from pyrite is a common accessory. Phenocrysts of biotite and feldspar were present in minor amounts (less than 6 percent). The biotite is often corroded and may show partial alteration to hematite. The feldspar phenocrysts are completely replaced by calcite and kaolinite (determined by XRD) but the idiomorphic outlines are retained.

The presence of kaolinite, the paucity of sodium (average less than 0.9 percent  $\text{Na}_2\text{O}$ ), and the corroded condition of the feldspar phenocrysts indicate that the rhyolites have been highly altered.

## Explanation of Plate 22 and Plate 23

Plate 22. Photomicrograph of intergranular diabase X46, polarizer at 45 degrees to analyzer. This diabase has undergone moderate alteration. Brown laths of plagioclase are altered to albite (by microprobe); the clinopyroxene (purple birefringence) has been partially altered to chlorite. The interstitial material is chlorite (white with tinges of violet.)

Plate 23. Photo of rhyolite sill (R) in the Cretaceous limestones of the Sierra del Cuervo. View is toward the west.

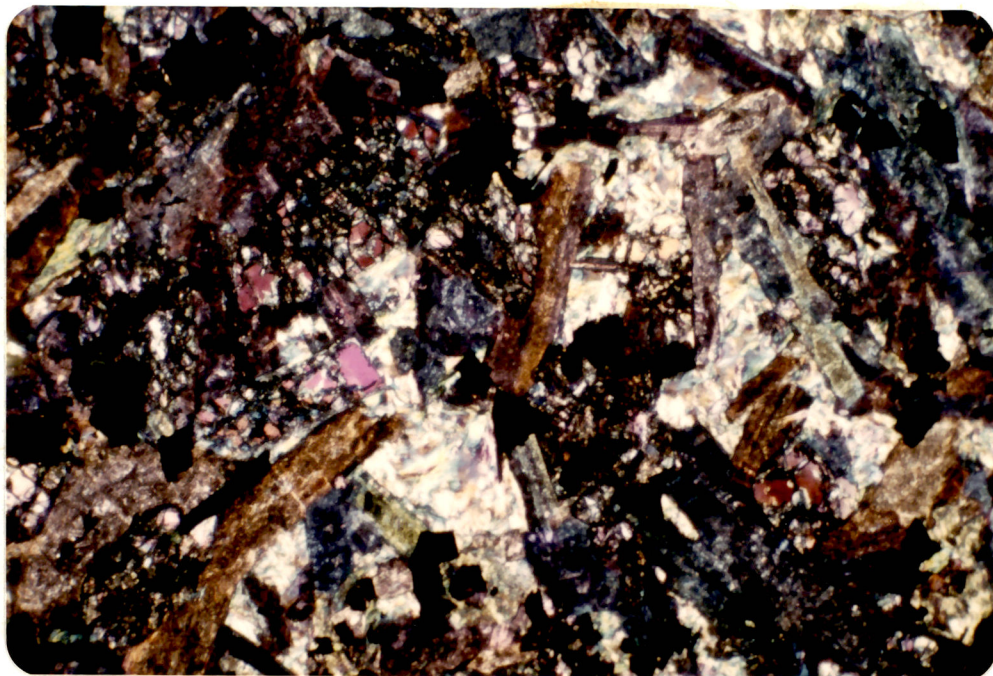


Plate 22



Plate 23



GRANODIORITE

This unit crops out as spheroidal boulders in the north-central portion of the field area (Plate 24). In hand specimen, the granodiorite is light gray, fine to medium grained, and speckled with biotite. Small white plagioclase phenocrysts are often visible against the darker groundmass. The granodiorite has a hypidiomorphic granular texture. Normally zoned phenocrysts of andesine ( $An_{30.6}$ ) are the dominant constituent (Appendix 1). The feldspar laths may range up to 3.5 mm in length and they are moderately sericitized. They may also be partially replaced by calcite. Quartz and orthoclase grains are restricted to the groundmass and they are generally less than 0.2 mm in diameter. Biotite crystals, averaging 0.75 mm but ranging up to 1.5 mm in length, are present in minor amounts. Alteration of biotite to chlorite is minor.

This unit is dated as Paleocene by K-Ar (Table 1). It intruded the Cretaceous limestones producing extensive thermal metamorphism. Regional evidence of young block faulting suggests that the granodiorite was probably emplaced prior to the faulting, but the field relations are not definitive.



Plate 24. Outcrop of spheroidally weathered boulders of the Paleocene granodiorite. This outcrop is located near the downfaulted block at map coordinates 3,201,150 north and 402,180 east.

### Rara Formation

The Rara Formation (Ramirez and Acevedo, 1957), also called the Villa Aldama Formation (Lopez-Ramos, 1969), is divided into two units. One is a highly folded and sheared turbidite sequence which consists of interbedded fine-grained quartz-rich sandstones and phyllitic shales (Plate 21). This unit also contains a meter-thick bed of strongly sheared, pebbly arkosic graywacke with shale chips and graded bedding. The other unit consists of interbedded fine-grained sandstones and mudstones with occasional beds of micritic limestones. These rocks are not as highly deformed as the turbidites. This less deformed unit is unconformably overlain by the flat-lying Cretaceous rocks (Fig. 3).

The Rara Formation has been assigned an Early Permian age (Wolfcampian) on the basis of fusilinids in the turbidite sequence (Mellor, 1978, 1981). However, phyllitic xenoliths which resemble shales from the Rara Formation occur in the post-metamorphic pegmatite (Plate 14). These xenoliths may represent shale which is from an extraneous location and which is unrelated to the Rara Formation. It is also possible that these xenoliths were derived from a shaly Precambrian section of the Rara that is in tectonic or sedimentary contact with the Upper Paleozoic part of the unit.

### Cretaceous Carbonates

The Sierra del Cuervo, on the western boundary of the study area, consists of 400-500 meters of cliff-forming Cretaceous strata (Plate 11). Three formations are present: the Las Vigas (Albian); the Cuchillo (Albian); and the Aurora (Aptian) (Tovar and Valencia, 1974). The descriptions of these formations (Tovar and Valencia, 1974) correlate well with the sedimentary units observed in the Los Filtros area. The lowermost Cretaceous unit is the Las Vigas Formation (Fig. 3). The Las Vigas is the thinnest of the three, and it consists of flat-lying interbedded siltstones and reddish shales. These unconformably overlie the Rara Formation. The Las Vigas grades upward into the Cuchillo Formation which consists of thickly bedded limestone, shale, muddy limestones, and a 3-5 meter-thick bed of anhydrite. The limestones are biomicrites which are locally rich in milliolid foraminifera and echinoderm fragments. The uppermost unit is the Aurora Formation. It consists primarily of massive, rudistid-bearing biomicrite that forms the prominent cliffs at the crest of the range.

### Contact Metamorphic Rocks (Skarn)

Intrusion of the granodiorite into Cretaceous limestones produced extensive marbles and more localized areas of calcsilicate rocks. The marble is fine- to coarse-grained and is light blue in color. It has been mined as decorative stone. The calcsilicate minerals are mainly wollastonite and grossularite which occur in highly variable grain sizes. A coarse-grained assemblage is found along the granodiorite-limestone contact. Boulder-size garnet aggregates are found in association with bladed crystals of wollastonite which are up to a foot in length (Plate 25). A fine-grained assemblage is associated with grayish-green felsic dikes which are exposed along the walls of the abandoned quarries. These dikes were formed by the injection of siliceous magma and volatiles into the surrounding limestone and shale. Abundant shale, chert, and limestone fragments were incorporated into these dikes. Away from the edges of the dikes the wall rocks grade laterally from fine-grained wollastonite to grossularite to pale-blue marble.



Plate 25. Bladed wollastonite crystals in the contact-metamorphic aureole produced by the intrusion of the Paleocene granodiorite into Cretaceous limestone.



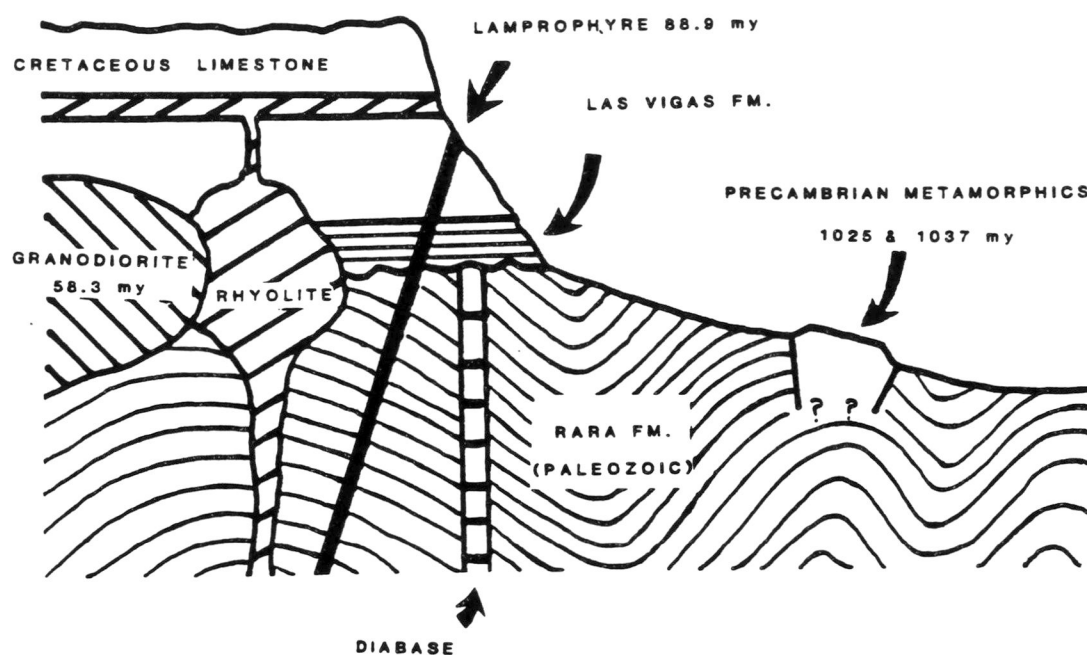


Figure 3. This diagram demonstrates the radiometric and relative ages of the major rock units in the Los Filtros area.

Table 1. K-Ar Age Data for Various Los Filtros Rock Types.

| sample<br>material | lat N<br>long W         | coord. N<br>coord. E | K%               | $^{40}\text{Ar}^*$<br>% | $^{40}\text{Ar}^*$<br>$\times 10^{-6}$<br>scc/g | Age, my<br>$\pm$ (1 ) | Notes, References,<br>DETENAL Map                                                                        |
|--------------------|-------------------------|----------------------|------------------|-------------------------|-------------------------------------------------|-----------------------|----------------------------------------------------------------------------------------------------------|
| 7-8-3<br>biot      | 28°56.19'<br>106°00.22' | 3,201,150<br>402,180 | 7.040<br>7.175   | 93                      | 16.37                                           | 58.3<br>(0.9)         | Los Filtros area, intrusive<br>biotite granodiorite; H13C56                                              |
| 7-8-1<br>biot      | 28°55.87'<br>105°59.32' | 3,200,615<br>403,610 | 7.612<br>7.736   | 95                      | 27.17                                           | 88.9<br>(1.4)         | Los Filtros area, phlogopite-<br>clinopyroxene lamprophyre<br>dike in Precambrian block;<br>H13C57       |
| CM-500<br>musc     | 28°55.87'<br>105°59.57' | 3,200,610<br>403,200 | 9.162<br>9.107   | 99<br>99                | 441.4<br>441.4                                  | 948<br>(14)           | Los Filtros area, pegmatite<br>that intrudes Precambrian<br>block; H13C57                                |
| 7-3-3<br>hbld      | 28°55.87'<br>105°59.37' | 3,200,598<br>403,520 | 1.307<br>1.297   | 99<br>99                | 69.86<br>69.68                                  | 1025<br>(21)          | Los Filtros area, amphibolite<br>dike in Precambrian block;<br>H13C57                                    |
| 7-3-4<br>hbld      | 28°55.89'<br>105°59.34' | 3,200,640<br>403,556 | 0.5677<br>0.5651 | 97<br>97                | 31.21<br>30.49                                  | 1037<br>(21)          | Los Filtros area, amphibolite<br>dike with minor epidote and<br>chlorite in Precambrian block;<br>H13C57 |

Analyses performed by Dr. Fred W. McDowell, University of Texas at Austin.

## GEOCHEMISTRY

Twenty-eight samples from ten major rock units were analyzed. The major elements and the following trace elements, Rb, Sr, Y and Zr, were determined by XRF for twenty-four of these samples. Eight samples (including four previously analyzed by XRF) were analyzed for their major element contents utilizing atomic absorption techniques by Skyline Laboratories Inc. The major element data for the duplicate samples analyzed by both XRF and AAS are given in Appendix 3. Skyline Laboratories Inc. determined  $\text{Na}_2\text{O}$ ,  $\text{CO}_2$  and  $\text{H}_2\text{O}$  for all the samples, and  $\text{MgO}$ ,  $\text{P}_2\text{O}_5$  and selected trace elements for some of the samples. Three USGS standards (G-2, AGV-1, BCR-1) were analyzed by XRF for the major elements and for the trace elements Rb, Sr, Y and Zr. The major element values determined for these standards are compared to the literature values (Appendix 4). The major and selected trace element values for the twenty-eight samples are given in Appendix 2. Significant chemical characteristics and relationships for some of the units are discussed below.

### Amphibolites

Eight amphibolite samples, including two metagabbros, two porphyritic metabasalts and four metabasalts, were chemically analyzed. The analyses compare favorably with the average composition of their proposed parent rocks as given by Cox and others (1979). The metagabbro closely matches the composition of an average gabbro. The metabasalts have higher iron and lower calcium and lower aluminum contents than average basalts.

Abundant potassium and sodium relative to the low silica values of the amphibolites is noteworthy. When the samples are plotted on an alkali-silica diagram (Fig. 4), they fall well within the field for alkaline magmas. However, the metasomatic introduction of sodium and potassium cannot be excluded as a possible explanation for the alkali enrichment.

On the alkali-silica diagram the metabasalts cluster with the younger unmetamorphosed Los Filtros diabbases. The metagabbros and the porphyritic metabasalts each define separate fields. The fact that the amphibolites define three distinct fields on the alkali-silica diagram supports the interpretation that they are the metamorphosed products of three different original rock types.

#### Precambrian Felsic Rocks

Six samples of metagranites were analyzed. Two of the samples (6-24-3 and 6-24-4) were intensely sheared and silicified metagranites. These samples were taken near the tectonic contact of a Precambrian block and the Rara Formation. The intensely sheared and silicified nature of these rocks is reflected in their high silica and low aluminum contents (Appendix 3).

One sample of biotite gneiss and one of plagioclase-pegmatite were also analyzed. The plagioclase-pegmatite is rich in calcium, sodium, and the trace elements Y and Zr (Appendix 2). Enrichment in Y and Zr is compatible with the late-stage metamorphic or late-stage igneous origins as previously proposed.

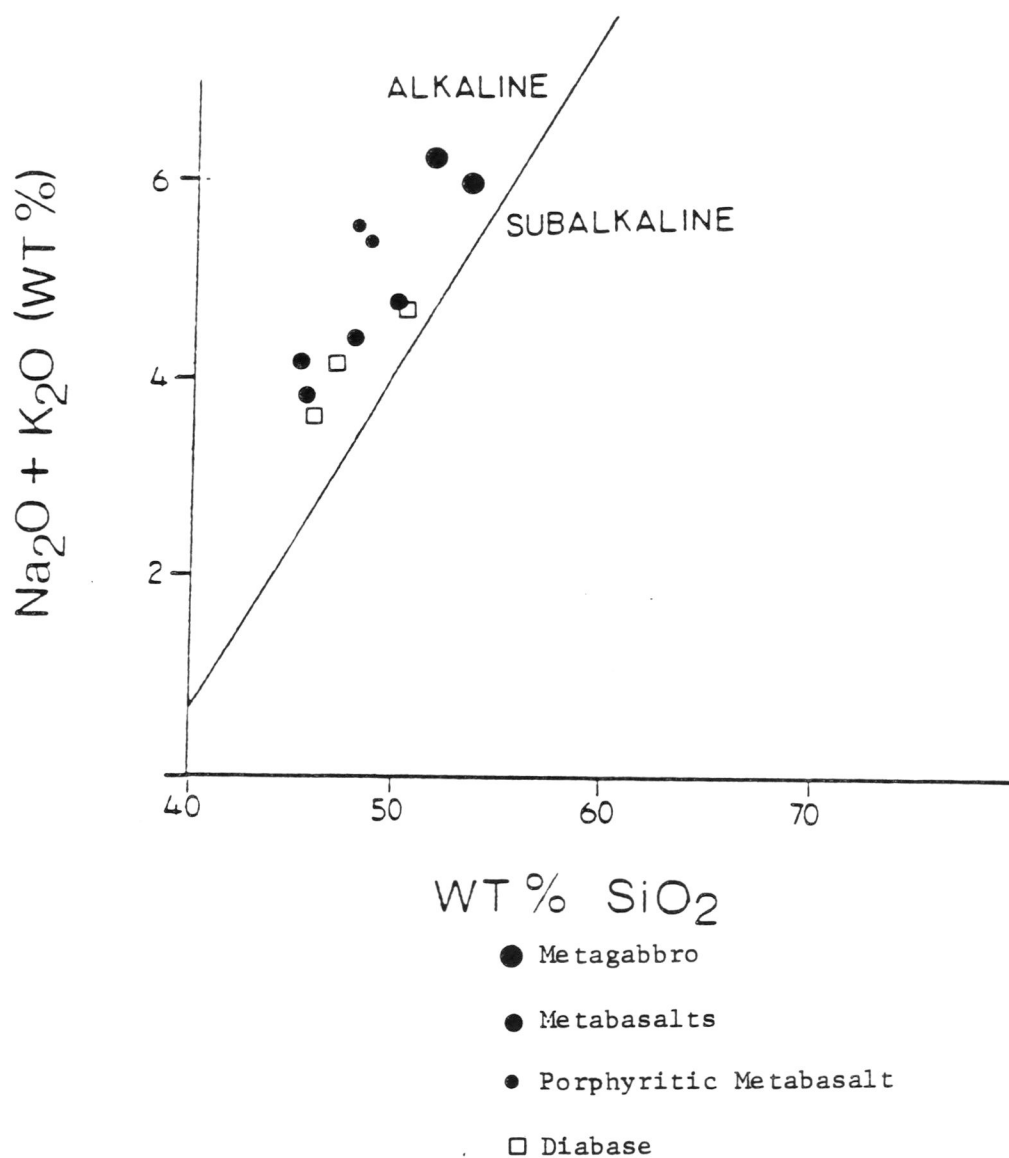
### Rhyolite

The rhyolites of the study area have higher  $\text{Al}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ ,  $\text{H}_2\text{O}$ , and lower  $\text{Fe}_2\text{O}_3$  and  $\text{Na}_2\text{O}$  than the average rhyolites of Cox and others (1979). The extremely low sodium and iron contents of the Los Filtros rhyolites are probably the result of alteration. The high  $\text{Al}_2\text{O}_3$  content of these rhyolites is consistent with the presence of kaolinite.

### Diabase Dikes

The diabase dikes in the study area are similar in composition to the average continental rift alkali basalts of Condie (1979). The diabases plot well within the alkaline field on an alkali-silica diagram (Fig. 4).

Figure 4. Alkali-silica diagram of amphibolite and diabase samples. Alkaline-sub-alkaline boundary after MacDonald (1968).





## SUMMARY

Several outcrops of Precambrian crystalline rocks are exposed in the Los Filtros area. These rocks consist primarily of amphibolites and metagranites which cooled down from amphibolite facies metamorphism about 1030 million years ago. They were emplaced into the Rara Formation as tectonic blocks probably during the Late Paleozoic collisional event which produced the Ouachita tectonic belt. The Rara and the Precambrian rocks were then intruded by Late Paleozoic to early Cretaceous diabase dikes. The Rara-Precambrian terrane was eroded, and subsequently covered by Cretaceous sedimentary rocks during the subsidence of the Chihuahua trough. Late Cretaceous to Paleocene rhyolite, granodiorite and lamprophyres cut the entire stratigraphic sequence.

## CONCLUSIONS

- 1) Coronas and relict igneous minerals and textures in some of the Precambrian amphibolites indicate that these rocks were metamorphosed under high load-low differential stress conditions.
- 2) Shale xenoliths in a Precambrian pegmatite suggest the faint possibility that the Rara Formation may consist in part of allochthonous Precambrian shale in sedimentary or tectonic contact with a Paleozoic unit.
- 3) Some of the diabase dikes which intrude the Precambrian rocks may be part of the allochthonous blocks. These dikes are possibly older than Paleozoic in age.
- 4) The Rara Formation and associated Precambrian blocks may be part of the Ouachita orogenic belt (Fig. 5). The Rara may have been part of a sediment prism along the southern edge of North America, seaward of Grenvillian crystalline rocks. When South America collided with North America the Rara was deformed and thrust faulted, possibly incorporating several tectonic slivers of the Grenvillian basement. When South America receded these rocks were left along the edge of North America, forming part of the Ouachita fold belt.

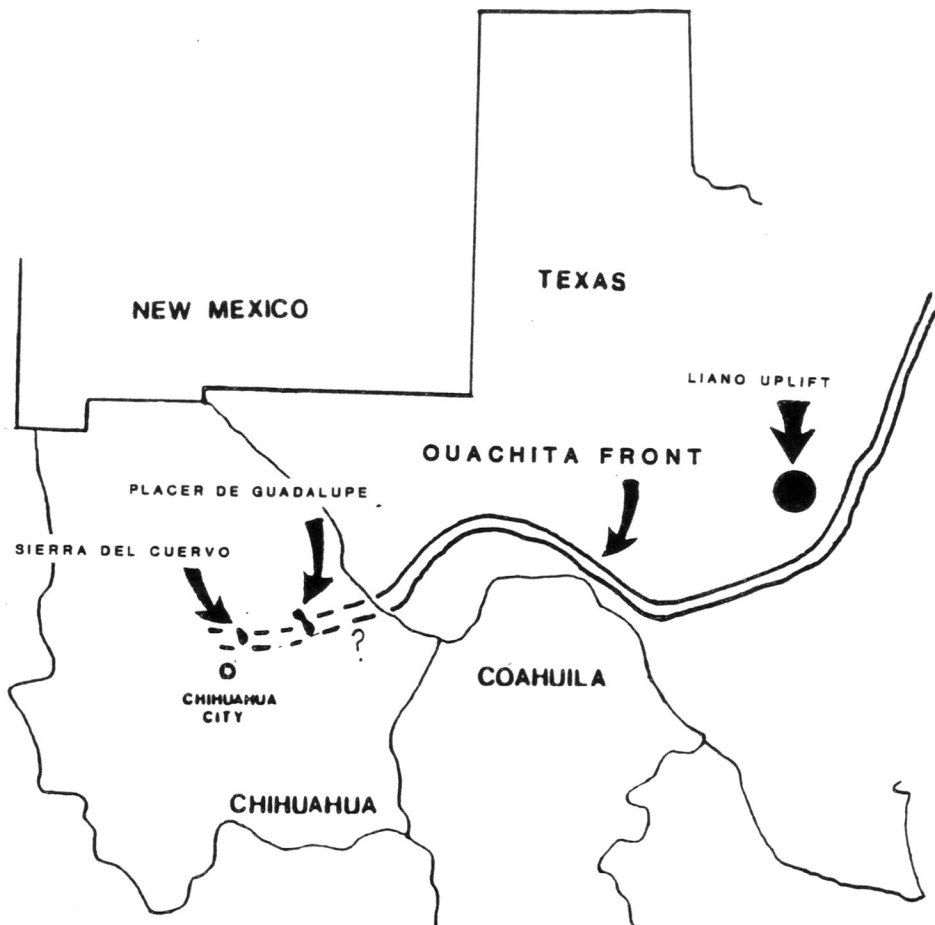


Figure 5. This map shows the position of the Ouachita front in Texas and its possible location in north-central Mexico. Paleozoic sediments crop-out on strike with the Ouachita front in the Sierra del Cuervo and at Placer de Guadalupe. The Llano uplift is on the continental side of the Ouachita front and it contains metamorphic rocks of Grenvillian age, similar to those at Los Filtros.

## REFERENCES CITED

- Bachinski, S.W., and Scott, R.B., 1979, Rare earth and other trace element contents and the origin of minettes (mica-lamprophyres): *Geochim et Cosmochin Acta*, v. 43, p. 93-100.
- Bridges, L.W., 1970, Paleozoic history of the southern Chihuahua tectonic belt, in, *The Geologic Framework of the Chihuahua Tectonic Belt: West Texas Geological Society Publication* 71-59, p. 47-67.
- Buddington, A.F., 1939, Adirondack igneous rocks and their metamorphism: *Geological Society of America, Memoir* 7, 354p.
- \_\_\_\_\_, 1952, Chemical petrology of some metamorphosed Adirondack gabbroic, syenitic and quartz syenitic rocks: *American Journal of Science*, v. 37, p. 37-84.
- Condie, K.C., 1979, Plate tectonics and crustal evolution: Pergamon Press, Inc., Elmsford, New York.
- Cooper, A.F., 1979, Petrology of ocellar lamprophyres from Western Otago, New Zealand: *Journal of Petrology* v. 20, p. 139-163.
- Cox, K.G., Bell, J.D., and Pankhurst, R.J., 1979, The interpretation of igneous rocks: Allen and Unwin, Inc., Winchester, Mass., 446p.
- Ferguson, J., and Currie, K.L., 1971, Evidence of liquid immiscibility in alkaline ultrabasic dikes at Callander Bay, Ontario: *Journal of Petrology*, v. 12, p. 561-585.
- Goodell, P.C., 1981, Geology of the Pena Blanca uranium deposits, Chihuahua, Mexico, in *Uranium in Volcanic and Volcaniclastic Rocks: AAPG studies in Geology* 13, p. 275-291.
- Griffen, W.L., and Heier, K.S., 1973, Petrological implications of some corona structures: *Lithos*, v. 6, p. 315-335.
- Higgins, M.W., 1971, Cataclastic rocks: U.S. Geological Survey Professional Paper 687, 97p.
- Huang, W.T. and Merritt, C.A., 1952, Petrography of the troctolite of the Wichita Mountains, Oklahoma: *American Mineralogist*, v. 39, p. 549-565.
- Lopez-Ramos, E., 1969, Marine Paleozoic rocks of Mexico: *American Association of Petroleum Geologists Bulletin*, v. 53, p. 2399-2417.
- MacDonald, G., 1968, Composition and origin of Hawaiian lavas: *Geological Society of America, Memoir* 116, p. 447-552.

- Mellor, E.L., 1978, A structural and petrographic study of Permian rocks near Villa Aldama, Chihuahua, Mexico: M.S. thesis Texas Christian University, Fort Worth, TX.
- \_\_\_\_\_, 1981, Petrology of late Paleozoic basinfill sandstone, north-central Mexico: Geological Society of America Bulletin, v. 92, p. 367-373.
- McHone, J.G., and Corneille, E.S., 1981, Alkalic dikes of the Lake Champlain Valley: in The Geology of the Lake Champlain Basin and Vicinity, Detenbeck, J.C., editor, Vermont Geology. v. 1, p. 16-21.
- Murthy, M.V.N., 1958, Coronites from India and their bearing on the origin of coronas: Geological Society of America Bulletin, v. 68. p. 23-38.
- Pearson, B.T., Foley, E., Bridges, L.W., and Diaz, T.G., 1964, Stratigraphy, structure, and geologic history of the Mina Plomosas -- Placer de Guadalupe area, in Geology of the Mina Plomosas -- Placer de Guadalupe area, Chihuahua, Mexico: West Texas Geologic Society, Guidebook no. 65-59, p. 37-39.
- Philpotts, A.R., 1976, Silicate liquid immiscibility: Its probable extent and petrogenetic significance: American Journal of Science, v. 276, p. 1147-1177.
- Phillips, E.R., 1974, Myrmekite -- one hundred years later: Lithos, v. 7, p. 181-194.
- Phillips, E.R., and Carr, G.R., 1973, Myrmekite associated with alkali feldspar megacrysts in felsic rocks from New South Wales: Lithos, v. 6, p. 245-260.
- Ramirez, J., and Acevedo, F., 1957, Notas sobre la geologia de Chihuahua: Boletin de la Asociacion Mexicana de Geologos Petroleros, v. 9, no. 9-10, p. 583-777.
- Reynolds, R.C., and Fredrickson, A.F., 1962, Corona development concept: Geological Society of America Bulletin, v. 73, p. 59-71.
- Rock, N.M.S., 1977, The nature and origin of lamprophyres: some definitions, distinctions, and derivations: Earth Science Reviews, v. 13, p. 123-169.
- Sederholm, J., 1916, On synantectic minerals: Comm. Geol. Findlande Bulletin 48, p. 1-59.
- Shand, S.J., 1945, Coronas and coronites: Geological Society of America Bulletin, v. 56, p. 247-266.
- Spry, A., 1969, Metamorphic textures: Pergamon Press, Inc., Elmsford, New York.

- Sutton, J., and Watson, J., 1951, Varying trends in the metamorphism of dolerites: Geological Magazine, v. 88, p. 25-35.
- Tovar, R.J., and Valencia, R.J., 1974, Road log, Ojinaga to Chihuahua City, in Geologic field trip through the states of Chihuahua and Sinaloa, Mexico: West Texas Geological Society Publication 74-63, p. 7-43.
- Turner, F.J., 1951, Observations of twinning in metamorphic rocks: American Mineralogist, v. 36, p. 581-589.
- Tuttle, O.F., and Bowen, N.L., 1958, Origin of granite in light of experimental studies: Geological Society of America, Memoir 74, 153p.
- Wilcox, R.E., and Poldervaart, A., 1958, Metadolerite dike swarm in Bakersville-Roan Mountain Area, North Carolina: Geological Society of America Bulletin, v. 69, p. 1325-1368.



Appendix 1. AVE Modal Analyses of Mineral Assemblages for Selected Rock Types.

|               | A    | B    | C    | D    | E    | F    | G    | H    |
|---------------|------|------|------|------|------|------|------|------|
| Vein Quartz   | 4.0  | 5.0  | --   | --   | --   | --   | --   | --   |
| Quartz        | 28.4 | 21.0 | 15.4 | 20.0 | 4.3  | 2.5  | acc. | 25.0 |
| Plagioclase   | 28.8 | 45.2 | 57.6 | 34.0 | 60.0 | 38.0 | 43.8 | 41.5 |
| K-Spar        | 35.0 | 20.0 | 2.0  | 35.5 | --   | --   | --   | 25.2 |
| Hornblende    | --   | --   | 15.6 | 8.0  | 28.8 | 52.2 | 51.5 | --   |
| Clinopyroxene | --   | --   | --   | --   | --   | 1.0  | acc. | --   |
| Biotite       | acc. | 7.1  | --   | 1.5  | --   | acc. | acc. | 4.0  |
| Chlorite      | 1.0  | acc. | 7.4  | acc. | 2.9  | 2.2  | acc. | acc. |
| Epidote       | acc. | --   | 1.2  | --   | 2.6  | acc. | 1.5  | --   |
| Garnet        | --   | --   | --   | --   | --   | acc. | --   | --   |
| Calcite       | 1.0  | acc. | --   | --   | --   | acc. | --   | 3.0  |
| Sphene        | acc. | acc. | acc. | acc. | acc. | acc. | 1.2  | acc. |
| Zircon        | acc. | acc. | acc. | acc. | --   | --   | --   | acc. |
| Opagues       | acc. | acc. | acc. | acc. | acc. | 2.2  | acc. | acc. |
| Sericite      | acc. | acc. | acc. | acc. | acc. | acc. | acc. | acc. |
| Apatite       | acc. | --   | acc. | acc. | acc. | acc. | acc. | acc. |

A = Recrystallized Granite

B = Biotite Gneiss

C = Hornblende Gneiss

D = Granite Gneiss

E = Metagabbro

F = Metadiabases

G = Porphyritic Metabasalt

H = Grandiorite

acc. = accessory = less than 1.0%

Appendix 2. Major and Trace Element Analyses.

| Sample No.                      | Recrystallized Granites |        |         |        | Sheared Granites |        | Biotite<br>Gneiss | Plagio-<br>Pegmatite |
|---------------------------------|-------------------------|--------|---------|--------|------------------|--------|-------------------|----------------------|
|                                 | 6-22-3                  | 6-15-2 | 6-24-13 | 6-16-2 | 6-24-4           | 6-24-3 | FG-1              | G-24-17              |
| SiO <sub>2</sub>                | 73.71                   | 76.38  | 76.44   | 76.19  | 80.80            | 81.76  | 69.22             | 62.97                |
| Al <sub>2</sub> O <sub>3</sub>  | 15.06                   | 13.43  | 14.52   | 13.02  | 11.91            | 10.66  | 15.55             | 12.97                |
| Fe <sub>2</sub> O <sub>3</sub>  | .10                     | .44    | .10     | 1.42   | .42              | .66    | 2.44              | 1.35                 |
| MgO*                            | .07                     | .08    | .07     | .41    | .23              | .33    | .89               | .67                  |
| CaO                             | .69                     | .70    | .62     | .56    | .52              | 1.45   | .81               | 7.93                 |
| Na <sub>2</sub> O*              | 4.50                    | 3.60   | 3.00    | 3.20   | 4.00             | 5.00   | 3.90              | 6.80                 |
| K <sub>2</sub> O                | 4.52                    | 4.80   | 6.14    | 4.70   | 2.43             | .03    | 3.50              | .45                  |
| MnO                             | .01                     | .01    | .02     | .04    | .01              | .04    | .06               | .08                  |
| TiO <sub>2</sub>                | .08                     | .09    | .06     | .29    | .18              | .30    | .28               | .27                  |
| P <sub>2</sub> O <sub>5</sub> * | --                      | --     | --      | --     | --               | --     | --                | --                   |
| CO <sub>2</sub> *               | .10                     | .10    | .10     | .10    | .10              | .70    | .10               | 4.6                  |
| H <sub>2</sub> O*               | .60                     | .30    | .60     | .70    | .60              | .40    | 1.4               | 1.0                  |
| Total                           | 100.07                  | 99.93  | 101.67  | 100.63 | 101.20           | 101.33 | 99.09             |                      |
| Rb (ppm)                        | 140                     | 147    | 202     | 115    | 69               | 15     | 133               | 3.6                  |
| Sr (ppm)                        | 201                     | 11     | 207     | 90     | 86               | 153    | 256               | 278                  |
| Y (ppm)                         | 25                      | 44     | nd      | 61     | 59               | 36     | 12                | 92                   |
| Zr (ppm)                        | 91                      | 174    | 58      | 244    | 284              | 71     | 117               | 618                  |
| Ba* (ppm)                       | --                      | --     | --      | --     | --               | --     | --                | 180                  |
| F* (ppm)                        | --                      | --     | --      | --     | --               | --     | --                | --                   |
| Cr* (ppm)                       | --                      | --     | --      | --     | --               | --     | --                | --                   |

\* Analysed by AAS (Skyline Laboratories, Inc.)

Appendix 2. Major and Trace Element Analyses (cont.)

| Sample No.                      | Metagabbro |        | Porphyritic Basalt |        | Metadiabases |       |       |        | Rhyolite |        |
|---------------------------------|------------|--------|--------------------|--------|--------------|-------|-------|--------|----------|--------|
|                                 | 7-3-2      | 6-22-7 | 6-28-1             | 6-19-8 | 6-19-2       | 7-3-6 | 7-6-1 | 6-22-8 | 6-8-6    | 7-5-1  |
| SiO <sub>2</sub>                | 52.18      | 52.34  | 48.62              | 48.54  | 46.51        | 46.35 | 50.89 | 48.45  | 70.80    | 73.76  |
| Al <sub>2</sub> O <sub>3</sub>  | 15.72      | 15.87  | 13.25              | 13.19  | 11.98        | 13.13 | 12.55 | 13.02  | 15.93    | 17.62  |
| Fe <sub>2</sub> O <sub>3</sub>  | 9.64       | 9.52   | 14.06              | 14.45  | 18.62        | 13.01 | 13.56 | 11.79  | .21      | .94    |
| MgO                             | 5.00       | 5.10   | 6.20               | 5.80   | 7.80         | 8.60  | 6.90  | 8.80   | .31*     | .11*   |
| CaO                             | 5.84       | 5.75   | 8.69               | 8.70   | 8.17         | 10.88 | 8.00  | 8.90   | 1.46     | .70    |
| Na <sub>2</sub> O*              | 4.60       | 4.30   | 3.60               | 3.90   | 2.90         | 2.40  | 3.50  | 2.70   | 1.50     | .27    |
| K <sub>2</sub> O                | 1.66       | 1.70   | 1.83               | 1.58   | 1.01         | 1.96  | 1.44  | 1.83   | 6.71     | 5.32   |
| MnO                             | .15        | .14    | .21                | .20    | .22          | .18   | .21   | .18    | .05      | .03    |
| TiO <sub>2</sub>                | .90        | .92    | 1.52               | 1.40   | 1.69         | .99   | .99   | .86    | .24      | .25    |
| P <sub>2</sub> O <sub>5</sub> * | .29        | .29    | .28                | .21    | .25          | .11   | .08   | .09    | .01      | --     |
| CO <sub>2</sub>                 | .50        | .20    | .10                | .10    | .50          | .20   | .10   | .40    | .30      | .10    |
| H <sub>2</sub> O                | 2.00       | 1.80   | 1.60               | 1.10   | 1.90         | 1.30  | 1.50  | 1.60   | 2.40     | 4.00   |
| Total                           | 98.48      | 97.93  | 99.96              | 99.17  | 101.55       | 99.11 | 99.72 | 98.62  | 100.06   | 102.90 |
| Rb (ppm)                        | 55         | 63     | 60                 | nd     | 4            | 50    | 30    | 27     | 210      | 238    |
| Sr (ppm)                        | 863        | 865    | 348                | 304    | 253          | 324   | 301   | 338    | 211      | 257    |
| Y (ppm)                         | 45         | 45     | 55                 | 49     | 50           | 34    | 41    | 15     | 39       | 42     |
| Zr (ppm)                        | 144        | 152    | 162                | 133    | 129          | 69    | 84    | 75     | 192      | 163    |
| Ba* (ppm)                       | 1100       | --     | --                 | --     | --           | --    | --    | --     | 1520     | 980    |
| F* (ppm)                        | --         | --     | 2300               | --     | --           | 900   | --    | --     | 660      | --     |
| Cr* (ppm)                       | --         | --     | --                 | --     | --           | 143   | --    | --     | --       | --     |

\* Analysed by AAS (Skyline Laboratories, Inc.)

Appendix 2. Major and Trace Element Analyses (cont.)

| Sample No.                      | Granodiorite |        | Diabases |        |       | Lamprophyres |        |         |        |       |
|---------------------------------|--------------|--------|----------|--------|-------|--------------|--------|---------|--------|-------|
|                                 | 7-8-3        | 6-8-15 | 6-24-16  | 6-28-3 | 6-3-6 | 7-3-1*       | 7-7-4* | 6-11-1* | 7-5-5* | 7-8-1 |
| SiO <sub>2</sub>                | 64.70        | 62.78  | 48.80    | 47.26  | 46.05 | 49.40        | 54.60  | 51.10   | 46.70  | 39.91 |
| Al <sub>2</sub> O <sub>3</sub>  | 15.54        | 15.96  | 13.24    | 12.87  | 13.21 | 12.60        | 16.40  | 15.30   | 14.70  | 12.19 |
| Fe <sub>2</sub> O <sub>3</sub>  | 2.96         | 3.01   | 10.70    | 12.60  | 12.50 | 7.70         | 6.20   | 6.60    | 11.00  | 14.94 |
| MgO                             | .30*         | .80*   | 5.30     | 5.90   | 6.40  | 3.60         | 1.40   | 2.10    | 5.40   | 7.80  |
| CaO                             | 2.86         | 4.09   | 10.78    | 10.06  | 11.13 | 9.50         | 5.30   | 6.30    | 7.60   | 12.38 |
| Na <sub>2</sub> O               | 4.30         | 3.30   | 3.40     | 2.80   | 2.80  | 2.90         | 4.90   | 3.30    | 3.10   | 2.40  |
| K <sub>2</sub> O                | 3.99         | 3.90   | 1.17     | 1.33   | .75   | 3.30         | 3.70   | 3.00    | 3.90   | 2.35  |
| MnO                             | .14          | .14    | .15      | .16    | .13   | .14          | .15    | .16     | .17    | .21   |
| TiO <sub>2</sub>                | .46          | .39    | 2.00     | 2.38   | 2.17  | 1.00         | .93    | .79     | 1.20   | 1.50  |
| P <sub>2</sub> O <sub>5</sub> * | --           | --     | .41      | .47    | .41   | .45          | .31    | .29     | .42    | .82   |
| CO <sub>2</sub> *               | 1.50         | 2.30   | 3.80     | 4.20   | .60   | 7.1          | 4.80   | 7.70    | 3.00   | 2.90  |
| H <sub>2</sub> O*               | 1.10         | 1.90   | 2.00     | 2.70   | 2.60  | 2.20         | 1.10   | 2.40    | 2.90   | 2.50  |
| Total                           | 97.85        | 98.57  | 101.39   | 102.73 | 98.75 | 99.89        | 99.79  | 99.04   | 100.09 | 99.09 |
| Rb (ppm)                        | 141          | 143    | nd       | 16     | nd    | 130          | 110    | 120     | 140    | 35    |
| Sr (ppm)                        | 340          | 264    | 357      | 434    | 464   | 360          | 710    | 370     | 560    | 1400  |
| Y (ppm)                         | 35           | 35     | 33       | 44     | 23    | --           | --     | --      | --     | 51    |
| Zr (ppm)                        | 202          | 172    | 116      | 153    | 123   | --           | --     | --      | --     | 165   |
| Ba* (ppm)                       | 1300         | 1160   | --       | --     | --    | 1370         | 1200   | 1100    | 460    | 730   |
| F* (ppm)                        | 390          | --     | --       | --     | --    | 880          | 660    | 1000    | 1200   | 1200  |
| Cr* (ppm)                       | --           | --     | --       | --     | --    | 90           | 5      | 4       | 4      | 13    |

\*Analysed by AAS (Skyline Laboratories, Inc.)

## APPENDIX III

Comparison of Major Element Analyses on four samples by XRF and commercial AAS.

|                                | G-28-1 |       | G-8-6 |       | 7-3-2 |       | 7-8-1 |       |
|--------------------------------|--------|-------|-------|-------|-------|-------|-------|-------|
|                                | AAS    | XRF   | AAS   | XRF   | AAS   | XRF   | AAS   | XRF   |
| SiO <sub>2</sub>               | 47.0   | 48.62 | 70.1  | 70.8  | 53.90 | 52.18 | 40.00 | 39.91 |
| TiO <sub>2</sub>               | 1.60   | 1.52  | 0.24  | 0.24  | 0.77  | 0.90  | 1.50  | 1.50  |
| Al <sub>2</sub> O <sub>3</sub> | 15.7   | 13.25 | 13.9  | 15.93 | 17.40 | 15.72 | 12.90 | 12.19 |
| Fe <sub>2</sub> O <sub>3</sub> | 12.60  | 14.06 | 0.70  | 0.21  | 8.20  | 9.64  | 15.30 | 14.94 |
| MnO                            | 0.23   | 0.21  | 0.05  | 0.05  | 0.15  | 0.15  | 0.24  | 0.21  |
| MgO                            | 6.00   | 6.20  | 0.31  | 0.45  | 4.30  | 5.00  | --    | --    |
| CaO                            | 8.50   | 8.69  | 1.10  | 1.46  | 5.80  | 5.84  | 11.70 | 12.38 |
| K <sub>2</sub> O               | 2.10   | 1.83  | 7.30  | 6.71  | 1.90  | 1.66  | 2.30  | 2.35  |

## APPENDIX IV

## (Accuracy of Major and Trace Element Analyses)

Comparison of literature values (lit.) and found values (found) for selected major and trace elements.

| MAJOR ELEMENTS                 |             |              |             |              |             |              |
|--------------------------------|-------------|--------------|-------------|--------------|-------------|--------------|
|                                | G-2         |              | AGV-1       |              | BCR-1       |              |
|                                | <u>lit.</u> | <u>found</u> | <u>lit.</u> | <u>found</u> | <u>lit.</u> | <u>found</u> |
| SiO <sub>2</sub>               | 69.19       | 68.52        | 59.72       | 60.15        | 54.85       | 55.55        |
| TiO <sub>2</sub>               | 0.50        | 0.49         | 1.05        | 1.07         | 2.22        | 2.25         |
| Al <sub>2</sub> O <sub>3</sub> | 15.40       | 15.20        | 17.22       | 15.38        | 13.68       | 13.30        |
| Fe <sub>2</sub> O <sub>3</sub> | 2.67        | 2.48         | 6.84        | 7.32         | 13.52       | 13.45        |
| MnO                            | 0.03        | 0.03         | 0.10        | 0.10         | 0.19        | 0.17         |
| MgO                            | .76         | --           | 1.53        | 1.55         | 3.46        | 3.46         |
| CaO                            | 1.98        | 2.05         | 5.00        | 4.80         | 6.98        | 6.55         |
| Na <sub>2</sub> O              | --          | --           | --          | --           | --          | --           |
| K <sub>2</sub> O               | 4.50        | 4.49         | 2.93        | 2.93         | 1.68        | 1.70         |

| TRACE ELEMENTS |             |              |             |              |             |              |
|----------------|-------------|--------------|-------------|--------------|-------------|--------------|
|                | G-2         |              | AGU-1       |              | BCR-1       |              |
|                | <u>lit.</u> | <u>found</u> | <u>lit.</u> | <u>found</u> | <u>lit.</u> | <u>found</u> |
| Rb             | 168         | 205          | 67          | 80           | 47          | 30           |
| Sr             | 479         | 528          | 660         | 648          | 330         | 310          |
| Y              | 12          | 57           | 26          | 48           | 46          | 57           |
| Zr             | 300         | 338          | 220         | 237          | 185         | 171          |