THE GEOLOGY OF THE WEST CENTRAL PORTION OF THE PATAGONIA MOUNTAINS, SANTA CRUZ COUNTY, ARIZONA

by

Seth Raynor Moger

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SIGNED: Sarah R. Moger

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

S. R. Titley
S. R. TITLEY
Professor of Geology

Aug 13, 1969
Date

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ABSTRACT

The Patagonia Mountains, Santa Cruz County, Arizona are a rugged north-northwest trending mountain range formed by a large igneous mass consisting of diorite, quartz monzonite, syenodiorite, granite, and granodiorite.

Prior to Laramide time a quartz monzonite intruded a hypothetical tonalite-alkali-syenite mass and produced syenodiorite through a process of assimilation. Dorite resulted from the concentration of the residue while the granite represents the minimum melting components from this intrusion.

Emplacement of the Laramide granodiorite intrusion created stresses which resulted in strong east-northeast and north-northwest fracturing. The major structure in the area is a north-northwest fault which divides barren and mineralized fracture directions. These fracture directions are pervasive in the mountain range and provided the channelways for ascending hydrothermal solutions and the deposition of various metallic minerals during the magmatic history of the granodiorite.

Several quartz monzonite breccia structures, located within the granodiorite, are moderately mineralized. These breccia structures are caused by collapse as a consequence of magma withdrawal and reaction with the residual liquids in the magma.

Alteration minerals include: quartz, sericite, and epidote, with quartz being the most pervasive. West of the front range fault, quartz and epidote are pervasive while sericite is confined to mineralized

fractures. East of the fault, epidote is minor while sericite and quartz are confined to mineralized fracture zones.

INTRODUCTION

Location and Extent of Area

The area studied in this thesis is located in the Palmetto Mining district on the west-central flank of the Patagonia Mountains, Santa Cruz County, Arizona. The region lies approximately 70 miles southeast of Tucson and is situated 5 miles south of Patagonia and 14 miles north of Nogales on Route 82 (Figure 1). The area is located in the Coronado National Forest in sections 3, 4, 9, 10, 15, and 16 of T. 23 S, R. 15 E., of the Nogales 15 minute quadrangle. The area is reached by an improved dirt road 4 miles south of Patagonia on Route 82.

Topography

The Patagonia Mountains are a rugged north-northwest trending chain of peaks situated in the Basin and Range physiographic province. Their topography is typical of the semiarid environment present in the Southwest. The western portion of the thesis area is a relatively flat pediment dissected by several major streams and numerous tributaries. To the east, the terrain is dominated by highly dissected and steep slopes and canyons. The elevation in the area varies from 4,160 feet to 6,369 feet, and although outcrops are sparse on the pediment, the steeper slopes provide excellent exposures.

Climate and Vegetation

The mean annual temperature is 62°F with the annual average extremes ranging from 45°F to 80°F. The warmest month is July (94.4°F

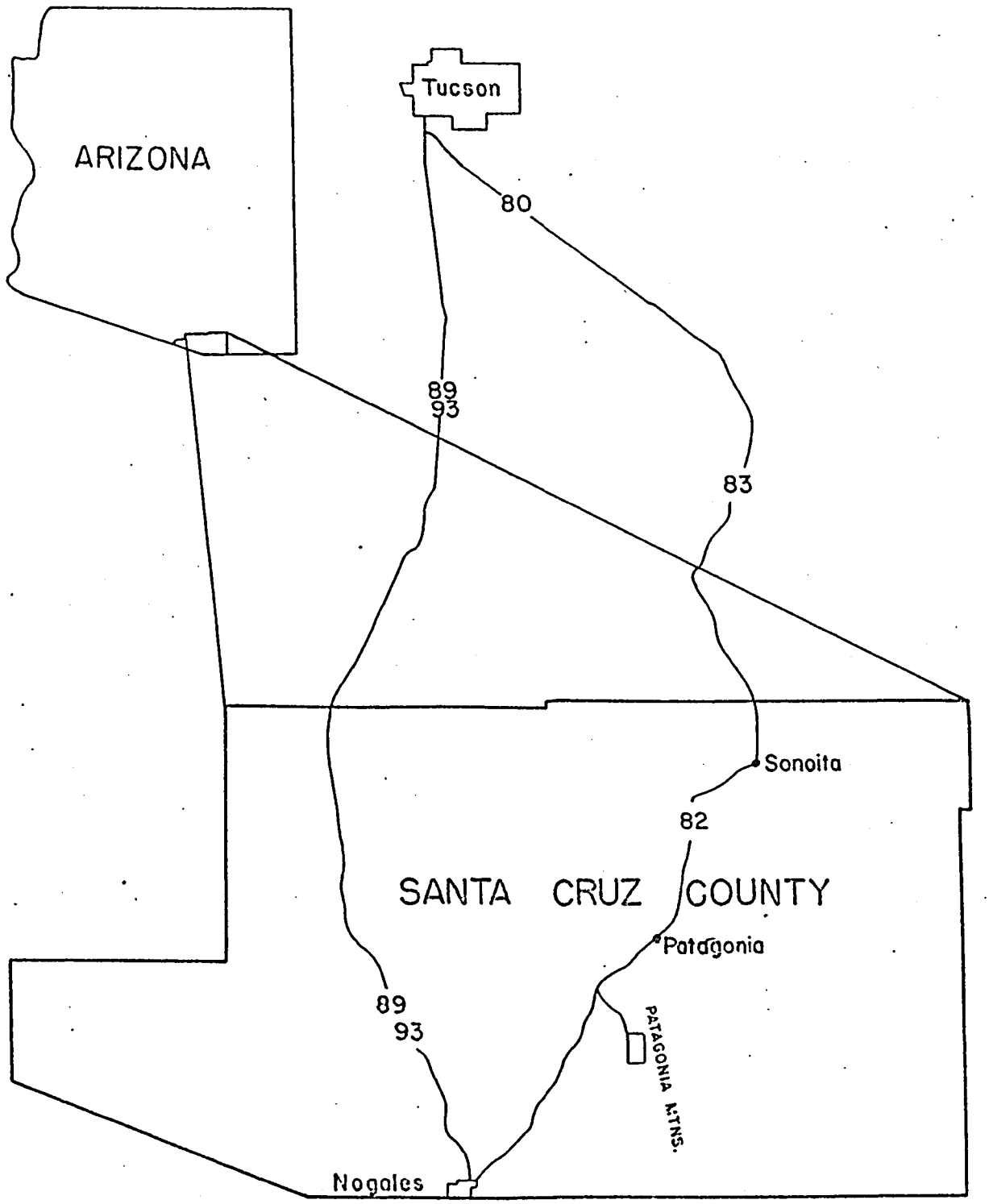


Figure 1. Index Map Showing Location of Thesis Area in Patagonia Mountains, Santa Cruz County, Arizona

mean maximum), and the coolest month is January (30°F mean minimum).

Precipitation in the Patagonia Mountains averages 17.19 inches per year, with nearly 50 percent of this being contributed by the rains of late July and August. A minor amount of snow falls during the winter months (H. V. Smith, 1945).

The vegetation in the area varies from the grasses and mesquite in the lower elevations to a greater abundance of semiarid vegetation at the higher elevations. The latter type consists of ocotillo, yucca, scrub oak, and manzanita.

Purpose of Investigation

Within the past several years, the Patagonia Mountains have been an extremely active area for geologic exploration. West Range Company, a subsidiary of Iso Mines, Ltd. and Noranda Mines of Canada, and The Anaconda Copper Corporation have conducted recent drilling operations. Both of these companies hold large claim groups in the central portion of the range as well as on the western flank and pediment.

Two intensely altered and mineralized breccia pipes situated in Ventura Canyon were drilled by West Range Company. The 1966 Iso Mines, Ltd. annual report reported the ore reserves of these breccias to be $\pm$ 3.6 million tons @ 0.402% MoS_2 and 0.22% Cu.

As the Patagonia Mountains are being explored extensively for base metals, detailed studies are necessary. Although the east flank of the mountains has been studied in detail, the west flank of the range has been poorly studied.

Numerous silver veins occur on the west flank of the Patagonia Mountains and are associated with a major structural fault. Mineralization also occurs near the crest of the range in numerous breccias as well as disseminations in the country rock.

This thesis reports the results of an investigation of the relationship of the mineralization to the local geology and adds to the general geology of the range.

Method of Investigation

Geologic mapping of this area commenced in February 1966, and approximately 40 days were spent in compiling the maps for this thesis. The base map (Figure 2, in pocket) of the area was made by enlarging a portion of the U.S. Geological Survey 15 minute Nogales quadrangle to a scale of 1 inch to 1,000 feet. Aerial photographs were used to supplement the field mapping, particularly to aid in some of the structural problems. The field work was supplemented by petrographic analysis of 50 thin sections.

Previous Work

The most comprehensive work done on the area is a report by Schrader (1915). This publication summarizes several years of reconnaissance work in the Patagonia and Santa Rita mountains. Additional articles reviewed for this study include: Brinsmade (1907), Dinsmore (1909), Probert (1914), Davis (1926), Butler (1938), Carpenter (1940), Johnson (1941), and G. E. Smith (1956). More recent works concerning the ore deposits of the Patagonia Mountains have been done by Kartchner (1944), Baker (1962), and Handverger (1963).

In addition to the above work, there have been numerous other publications concerning the ore deposits as well as the general geology of the Patagonia Mountains, but these have almost totally excluded the western side of the range.

IGNEOUS ROCKS

The west flank and pediment of the Patagonia Mountains are made up entirely of igneous rocks which are mapped as Precambrain on the Pima-Santa Cruz county geologic map. Five major rock types were mapped in this area (Figure 2, in pocket). Listed from oldes to youngest these include: diorite, quartz monzonite, syenodiorite, granite, and granodiorite. Within each unit there are various compositional and textural changes which have resulted from a complex origin. Although many of the contacts are sharp and well defined, there are many instances where the contacts are very gradational and difficult to map precisely.

Diorite

Description

The diorite is situated in the western portion of the area and constitutes approximately 5 percent of the exposures in the geologic area. The diorite is a fine- to medium-grained, inequigranular, holocrystalline, xenomorphic rock which occasionally exhibits a porphyroblastic texture. Its fresh surface varies from a light to dark gray, and it weathers readily to a light reddish brown.

The diorite is emplaced where there has been a great deal of complex intrusive activity accompanied by strong northeast and north-northwest fracturing. Throughout the diorite mass there are numerous pods of rock ranging in composition from granite to monzonite which are usually highly epidotized and silicified. These pods were too small to

map independently, and they are therefore mapped as a portion of the diorite complex (Figure 2, in pocket). The quartz monzonite intrusion has reacted with and assimilated the diorite in many areas, and thus the establishment of the exact contact is often quite difficult.

In using the term "assimilation" throughout this paper, I am referring to a complex process of reciprocal reaction between the intrusion and the country rock. While some of the minerals present in the wall.rock may become partially or completely melted and in this way incorporated into the liquid fraction of the magma, others are changed by a process of ionic exchange (reaction) into those crystalline phases with which the liquid was already saturated. I use the term "assimilation" primarily in the latter sense.

Within this region there are numerous fine-grained dikes varying in composition from rhyolite to andesite. These dikes trend north and northwest and parallel the fracture pattern in the area. Strong epidotization occurs along the contacts of these dikes with the country rock, and 1/16 to 1/8 inch epidote veinlets are commonly located in and along the dikes as well as in the wall rock.

Minor mineralization occurs along many of the northwest-trending fractures and diorite dikes, and several large mineralized veins in the diorite were the wites of past mining activity.

Petrography

The composition of the diorite is quite variable. Its average composition as determined from the microscopic study and measurement of five thin sections is:

Plagioclase	53%	Quartz	2%
Andesine An_{40}		Apatite	2%
Biotite	19%	Sphene	1%
Hornblende	10%	Opaques	1%
Orthoclase	6%	Epidote	tr
Chlorite	6%	Sericite	tr

The average diorite is xenomorphic granular and consists of more than 50 percent plagioclase (oligoclase-andesine) and 35 percent mafic minerals. The plagioclase grains are generally anhedral and exhibit a mosaiclike texture. The plagioclase occasionally exhibits normal and oscillatory zoning. The plagioclase grains are generally moderately sericitized and may be weakly epidotized, particularly where they are associated with mineralized fractures. Anhedral quartz and orthoclase are interstitial to the biotite and hornblende which occur as independent anhedral to subhedral grains. The hornblende varies from brown to green while the biotite is weakly chloritized.

There are two textural types of diorite. The most widespread is the massive fine-grained type which is common in the highly silicified and epidotized area west of the major north-northwest fault. Here the diorite is generally low in quartz, but near the quartz monzonite and granite contacts the quartz content increases and it approaches the composition of quartz diorite. The diorite is high in mafic minerals, particularly hornblende, and has a composition as shown in Table 1.

The biotite and chlorite are anhedral in the fine-grained type, but the hornblende may be characterized by thin, 1/16 inch, acicular crystals. This type of diorite is rich in plagioclase, and near the quartz

TABLE 1--Composition of Various Textural Phases (in Mineral Percentages)

	Granite				Quartz Monzonite			Granodiorite			Syenodiorite			Diorite		
	1	2	3	Av	2	3	Av	2	3	Av	2	3	Av	1	2	Av
Plagioclase	1	15	7	12	19	32	29	52	54	53	35	31	33	59	45	53
An%	28	29	28	28	34	31	31	31	32	31	31	34	32	42	38	40
Orthoclase	4	32	39	33	21	26	25	20	14	17	11	11	11	5	8	6
Quartz	23	40	29	36	40	23	26	17	24	20	2	3	2	2	2	2
Perthite		3	18	8	2	10	9									
Microcline		3	2	3												
Biotite	2	2	2	2	5	1	2	6	6	6	11	10	11	8	30	19
Chlorite	3	3	1	3	3	4	4	6	2	3	30	31	30	10	2	6
Hornblende	2										7	2	5	14	5	10
Epidote	64				tr	tr	tr				1		tr	1		tr
Sphene	tr	tr	1	tr		tr	tr				1	1	1		3	1
Apatite	tr	tr	1	tr	tr	tr	tr	1	tr	1	2	1	1	1	3	2
Zircon																
Sericite		4		1	3	2	3	tr	tr	tr	6	4	4	1		tr
Clay		1		1	4		1	tr	tr	tr	1		tr			
Opaque		tr	tr	1			1				1	2	2	1	2	1

Explanation of Phases: Phase 1 = fine-grained texture; Phase 2 = medium-grained texture; Phase 3 = coarse-grained texture.

monzonite contact the plagioclase becomes coarser grained and the diorite takes on a porphyroblastic texture. There does not appear to be any apparent zoning of this texture.

Epidotization of the diorite is generally moderate except in areas where diorite dikes are present and where the diorite is in contact with the quartz monzonite or granite. There is a minor amount of chlorite after biotite and weak to moderate sericitization and kaolinization associated with the mineralized veins in the diorite wall rock.

The second type of driorite is medium to coarse grained, equigranular, and very similar, texturally, to the syenodiorite. It is distinguished from the syenodiorite by euhedral biotite crystals and by a larger percentage of both biotite (30 percent in the diorite vs 11 percent in the syneodiorite) and plagioclase (45 percent in the diorite vs 35 percent in the syenodiorite). Although this type of diorite is rare, it serves to indicate the closeness in both the composition and texture of the diorite and the syenodiorite.

Quartz Monzonite

Description

Quartz monzonite is the major rock unit in this region and constitutes approximately 60 percent of the rock in the area mapped. It is generally a medium- to coarse-grained, inequigranular, holocrystalline, hypidiomorphic rock, which light pinkish brown on a fresh surface. Scattered aggregates of mafic minerals may give it a speckled appearance, which is quite similar to the speckled appearance of the granite. The

quartz monzonite weathers quite readily to a dull grayish brown and has a rounded rubbly texture much like the coarse-grained granite.

Petrography

The composition of the quartz monzonite varies from granite to quartz diorite owing to assimilation effects during its intrusive history. Its general composition as determined from six thin sections is

Plagioclase	29%	Sericite	3%
Andesine An_{31}		Biotite	2%
Quartz	26%	Clay	1%
Orthoclase	25%	Apatite	1%
Perthite	9%	Epidote	tr
Chlorite	4%	Sphene	tr

Petrographically the quartz monzonite is very similar to the granite except that there is a greater percentage of plagioclase (andesine) and perthite. The quartz monzonite is Also more highly sericitized than the granite.

The quartz monzonite if generally fresh. However, in a few minor areas it is rich in quartz and epidote, and there are some mineralized fractures which are bordered by moderate to strong selvages in the wall rock.

There are two types of quartz monzonite. The first is a medium-grained, equigranular, xenomorphic rock which is texturally equivalent to the second phase of the granite. This type of quartz monzonite occurs only in the western portion of the area in association with the medium-grained granite and the quartz and epidote rich granite. The contact

between the first phase of the quartz monzonite and the medium-grained granite is gradational in the western portion of the area, and the quartz monzonite becomes coarser grained farther from the contact. In the western portion of the area, this first phase of the quartz monzonite is differentiated from the medium-grained granite on the basis of a greater percentage of biotite and plagioclase and a smaller percentage of orthoclase in the quartz monzonite. Where this medium-grained phase of quartz monzonite is in contact with the diorite complex, the quartz monzonite contains several diorite inclusions. Along the quartz monzonite-granite contact there are several granitic dikes cutting the quartz monzonite.

The second phase of quartz monzonite is coarse grained, inequigranular, and exhibits subhedral plagioclase. Along the western edge of the map there are exposures where the quartz monzonite becomes pegmatitic with inch-long feldspars. The composition of the second phase varies as it approaches various other rock units (Table 1).

In the western portion of the area shown in Figure 2, the second phase of quartz monzonite contains small pods of assimilated diorite and is also cut by numerous granitic and dioritic dikes. It is in this area that epidotization is strongest.

The coarse-grained quartz monzonite contains numerous isolated inclusions of diorite in the central portion of the area. The contacts in this area vary from being very sharp and distinct to being extremely gradational due to various degress of assimilation (reaction). In the central portion of the area where the second phase of the quartz monzonite is in contact with the diorite, assimilation of the diorite by the quartz

monzonite has produced a more medium-grained quartz monzonite. In this area the quartz and plagioclase content of the quartz monzonite has increased. The mafic minerals are generally anhedral biotite and chlorite if medium-grained, but subhedral if coarse-grained. There is also an increase in hornblende as the rock becomes more dioritic.

In general, along the quartz monzonite-syenodiorite contact, the quartz monzonite remains coarse grained and the syenodiorite medium to coarse grained. In areas where the quartz monzonite has assimilated the syenodiorite, the quartz monzonite becomes medium grained, richer in mafics, and less rich in its quartz content.

In the central portion of the area shown on Figure 2 and within the main quartz monzonite mass, there are several large blocks or inclusions of diorite and syenodiorite. The majority of these blocks exhibit the effects of assimilation along their outer perimeters in three definite zones. Along the outer edge of the basic inclusion the size of the quartz and mafic crystals decreases while the plagioclase crystals maintain their original size and texture. In the central zone of assimilation within the basic inclusion, there is an increase in the percentage of mafic minerals and plagioclase and a decrease in the amount of quartz and orthoclase. The plagioclase maintains its size and coarse texture while the quartz and orthoclase become fine to medium grained. The inner core of the assimilated basic inclusion is essentially a medium-grained diorite-syenodiorite with approximately 30 to 40 percent mafic minerals. The biotite, chlorite, and hornblende are usually anhedral, but toward the southern edge of the mapped area they become subhedral within the core of the inclusion.

Along the northeast and southeast edge of the mapped area, the second phase of the quartz monzonite becomes mixed with the coarse-grained granite. The contacts in these areas are difficult to distinguish in the field because of the close compositional and textural similarities between the coarse-grained phases of the quartz monzonite and the granite. However, in thin section analysis the quartz monzonite is distinguished from the granite on the basis of a larger percentage of plagioclase and mafic minerals and a smaller percentage of orthoclase and quartz.

In the eastern portion of the mapped area where the quartz monzonite-granodiorite contact is approached, the quartz monzonite exhibits a decrease in grain size and in quartz content but an increase in the percentage of subhedral mafic minerals and plagioclase. The contact between the quartz monzonite and the granodiorite is generally very distinct, although there are several quartz monzonite inclusions within the younger intrusion near this contact. There are only minor assimilation effects on the quartz monzonite inclusions in this area.

In accordance with Bowen's Reaction Series (Bowen, 1956), the approximate order of separation and the normal crystallization of a magma proceed from the basic to the felsic to the felsic rocks. Although the diorite was not subject to complete melting at the temperature at which the quartz monzonite was in a molten state, there was a great deal of ionic reaction between the quartz monzonite and the basic complex. As mentioned above, large basic inclusions within the quartz monzonite exhibit the zonal effects of assimilation. Smaller basic inclusions have been partially or completely digested by the quartz

monzonite. There are also numerous diorite dikes and apophyses which cut the quartz monzonite, indicating that in places the diorite postdates the intrusive quartz monzonite.

Although the origin of these diorite dikes is uncertain, it appears that they may be explained by one of the following: (1) a reactivation of a portion of the diorite mass after a part of the quartz monzonite had crystallized, or (2) a younger diorite intrusion.

Syenodiorite

Description

The syenodiorite extends from the center of the mapped area eastward to the crest of the range. It constitutes about 20 percent of the rock in the mapped area and is closely associated spatially with the diorite. It is a medium- to coarse-grained, equigranular, holocrystalline, hypidiomorphic rock varying in color from a light grayish green to a grayish brown. Upon weathering it forms rounded, light gray boulders.

Its contact with the quartz monzonite and granodiorite are generally gradational. The syenodiorite has two textural varieties. A coarse-grained syenodiorite seems to dominate the central portion of the mapped area, whil a medium-grained type prevails in the eastern portion of the mapped area.

Petrography

The average composition of the syenodiorite as determined from eight thin sections is:

Plagioclase	33%	Quartz	2%
Andesine An_{32}		Opaques	2%
Chlorite	30%	Sphene	1%
Biotite	11%	Apatite	1%
Orthoclase	11%	Clay	tr
Hornblende	5%	Epidote	tr
Sericite	4%		

This rock is generally hydiomorphic granular, consisting of 33 percent sodic plagioclase and 45 percent mafics. The plagioclase grains are subhedral and locally exhibit strong sericitization. Anhedral orthoclase is weakly sericitized and kaolinized. Interstitial quarts is anhedral and varies from 0 to 7 percent but is usually less than 5 percent. Brown subhedral to euhedral biotite is in places weakly chloritized.

The composition of the two textural types remains relatively uniform throughout the entire complex, but toward the assimilated borders their composition becomes similar to the composition of the rock with which they are in contact. The first textural type of syenodiorite is medium grained and contains occasional plagioclase laths as well as subhedral biotite and chlorite. This type dominates the crest of the range where the syenodiorite is in contact with the younger granodiorite. This contact is gradational and is characterized in the composition of the syenodiorite by an increase in the plagioclase and quartz and a decrease in mafic minerals. Along this contact the grain size of the syenodiorite and the granodiorite is similar, but the granodiorite exhibits subhedral to euhedral biotite flakes which are lacking in the medium-grained syenodiorite.

The second textural phase of the syenodiorite is coarse grained and is similar in appearance to the coarse-grained quartz monzonite. The contact of this second phase of syenodiorite with the quartz monzonite varies from quite distinct to very gradational where assimilation has taken place. The gradational contact between the second phase of the syenodiorite and the quartz monzonite is characterized texturally in the syenodiorite by an increase in the grain size of biotite, chlorite, and hornblende and compositionally by an increase in the percentage of orthoclase and quartz and by an increase in the percentage of mafic minerals.

The coarser-grained syenodiorite is located primarily in the central portion of the mapped area. However, there is considerable overlap of the medium- and coarse-grained types in this region. In this central area, the composition of the syenodiorite is extremely variable, and where assimilation of the syenodiorite by the quartz monzonite has occurred, the contact between these two rock units is not distinct. Evidence for assimilation of the syenodiorite by the quartz monzonite is primarily in the form of textural and compositional changes within the syenodiorite. The syenodiorite exhibits a marked increase in quartz and a decrease in biotite, chlorite, and hornblende as the syenodiorite-quartz monzonite contact is approached. The syenodiorite also becomes coarser grained near its contact with the quartz monzonite.

Granite

Description

The granite is a fine- to coarse-grained, inequigranular, holocrystalline, xenomorphic rock and is relatively resistant to erosion. Its fresh surface varies from a light buff brown to a light grayish green and reveals a slight pinkish tinge due to the feldspar content. Where the mafic minerals are abundant, they tend to aggregate and impart a speckled appearance to the granite. The weathered granite varies from blocky in the fine-grained type to rubbly in its coarser phase. Generally, the weathered surface appears reddish brown.

Alteration of the granite is usually weak. However, moderate to strong sericitization of the feldspars imparts a slight porphyroblastic texture to the rock where cut by mineralized fractures. Very weak chloritization and kaolinization may accompany the sericitization along these mineralized fractures.

Petrography

Although the granite's composition and texture vary considerably, its general composition as determined from 17 thin sections is:

Quartz	36%	Biotite	2%
Orthoclase	33%	Sericite	1%
Plagioclase	12%	Clay	1%
Oligoclase	An_{28}	Opaques	1%
Perthite	8%	Epidote	varies
Microcline	3%	Sphene	tr
Chlorite	3%	Apatite	tr

The granite is generally hypidiomorphic granular. The subhedral sodic plagioclase and the anhedral potassic feldspar are generally coarse grained and are surrounded by medium-grained quartz. Biotite and chlorite are the only mafic minerals and occur as large, anhedral to subhedral flakes.

Where the granite is in contact with the diorite, the contacts are generally easy to distinguish. However, where the granite is in contact with the quartz monzonite, the contacts are more subtle and difficult to recognize. Various phases of the granite and quartz monzonite are similar in both composition and texture and appear to grade into each other almost imperceptibly.

The granite varies in both composition and texture and may be separated into three phases. The first phase is rich in epidote and quartz and exhibits an aplitic texture. It is equigranular and phaneric and varies from a light green to a pale gray. The second phase of granite varies from a fine-grained, equigranular, aplitic-textured rock to a medium-grained, inequigranular granitic rock. This second type acts as a boundary or border phase between the quartz monzonite and the more basic rock units in the area. This type of granite is also associated with the quartz monzonite in the small breccia outcrops in the granodiorite. The third phase of granite is a coarse-grained, inequigranular rock which exhibits subhedral plagioclase and subhedral to euhedral biotite crystals.

The epidote and quartz rich phase of granite is spatially associated with the diorite and quartz monzonite masses in the western portion of the thesis area. It is particularly prevalent where mineralization

occurs in the area. The second type of granite is associated with the quartz monzonite-diorite contact and the quartz monzonite-syenodiorite contact. The third phase of granite is located predominantly in the eastern portion of the mapped area where it is in contact with the granodiorite intrusion.

The first phase granite is atypical. It is characterized and distinguished from all other rock units by the large percentage of epidote and quartz (varying from 50 to 90 percent of the rock) and by the minor amounts of plagioclase, orthoclase, and mafic minerals. The second phase of granite is distinguished in composition from the third phase by its larger percentage of plagioclase, quartz, and mafic minerals (Table 1).

Both the composition and texture of the third phase of granite are similar to the coarse-grained quartz monzonite. However, the coarse-grained granite is distinguished from the coarse-grained quartz monzonite by a greater percentage of orthoclase and quartz and a smaller percentage of plagioclase and mafics. Where the third type of granite is in contact with the granodiorite, the granite is characterized by an increase in subhedral plagioclase and euhedral biotite. Along the granite's northern contact with the granodiorite, the subhedral plagioclase crystals form a conspicuous porphyroblastic texture. This texture is most pronounced where the granite is highly sericitized.

In general, both the granite-quartz monzonite and the granite-granodiorite contacts are gradational. These contacts are represented by subtle changes in the composition and texture of the various rock units over several hundred feet. To the north of the thesis area, the

granite becomes monzonitic in composition but retains its coarse texture.

Granodiorite

Description

The granodiorite, located on the eastern edge of the mapped area, is the youngest intrusive rock in the area and represents approximately 10 percent of the area mapped. It is a medium- to coarse-grained, holocrystalline, inequigranular, hypidiomorphic to idiomorphic rock. On a fresh surface it is light gray and upon weathering forms brownish-gray rounded boulders. It is generally characterized by subhedral to euhedral plagioclase and biotite grains, but the degree of crystallinity varies, depending upon whether it is medium or coarse grained and where it is located within the intrusive mass.

Although most of the granodiorite is fresh, there are several intensely sericitized zones in the northeast portion of the area. These zones follow a northeast fracture trend and are moderately mineralized with copper sulfides. In the northern portion of the mapped area, the granodiorite exhibits a porphyroblastic texture which has been enhanced by intense sericitization of the plagioclase laths.

Petrography

The composition of the granodiorite is quite uniform. The study of eight thin sections gives a general composition of:

Plagioclase	53%	Chlorite . . .	3%
Andesine An_{31}		Apatite	1%
Quartz	20%	Sericite . . .	tr
Orthoclase	17%	Opaque	tr
Biotite	6%		

The average granodiorite is hypidiomorphic granular and may be divided into two types based predominantly on its texture. The first is fine to medium grained and contains anhedral to subhedral plagioclase and mafics. It is slightly richer in orthoclase and less rich in quartz than the second type. Although there is an overlapping of these two textures, the first type is most common in the southern portion of the granodiorite intrusion.

To the north of the large breccia zone (Figure 2, in pocket) is a coarser type of granodiorite which is quartz rich and exhibits subhedral to euhedral plagioclase and biotite grains. It is in this area that there are several strongly altered zones and the granodiorite exhibits a porphyroblastic texture.

Petrology

The following discussion will be based on various diagrams prepared from modal analyses of the diorite, quartz monzonite, syenodiorite, and granite and also from visual estimation of the mineral percentages in thin sections.

There are two possible origins for the rocks in the thesis area which will be considered. First, it is possible that all rocks are related to each other in that they were derived from the same magma chamber.

Rocks originating in this manner would be related in time. From this one magma chamber the various rock units now present in the Patagonia Mountains were derived by differentiation of a single magma. The second possibility is that the rocks have a completely unrelated intrusive history and that there were separate intrusions unrelated in time. Within the context of the above two origins, it is possible that assimilation and/or metasomatic reaction between the early and late rocks may have accounted for some of the various rock units in the area.

For the purposes of this discussion the granodiorite is excluded because it is definitely a younger intrusive (Damon, 1965).

Data

Harker Variation Diagram. This diagram (Figure 3) was constructed by first calculating the weight percentage of each mineral and then calculating the modal chemical composition of each rock. After determining the chemical composition of the rock as expressed in oxides, each rock was plotted according to percentage of oxide versus percentage of silica.

Owing to the large percentage of chlorite alteration in the syenodiorite, I assumed that the chlorite formed from former biotite and thus the percentage of original biotite was taken as 41 percent in the construction of the Harker Variation Diagram.

A smooth line on the variation diagram generally indicates that the various rock units were probably formed through a process of differentiation (Turner and Verhoogen, 1960). The more that the line deviates from a smooth curve, the more likely it is that the rocks were formed by

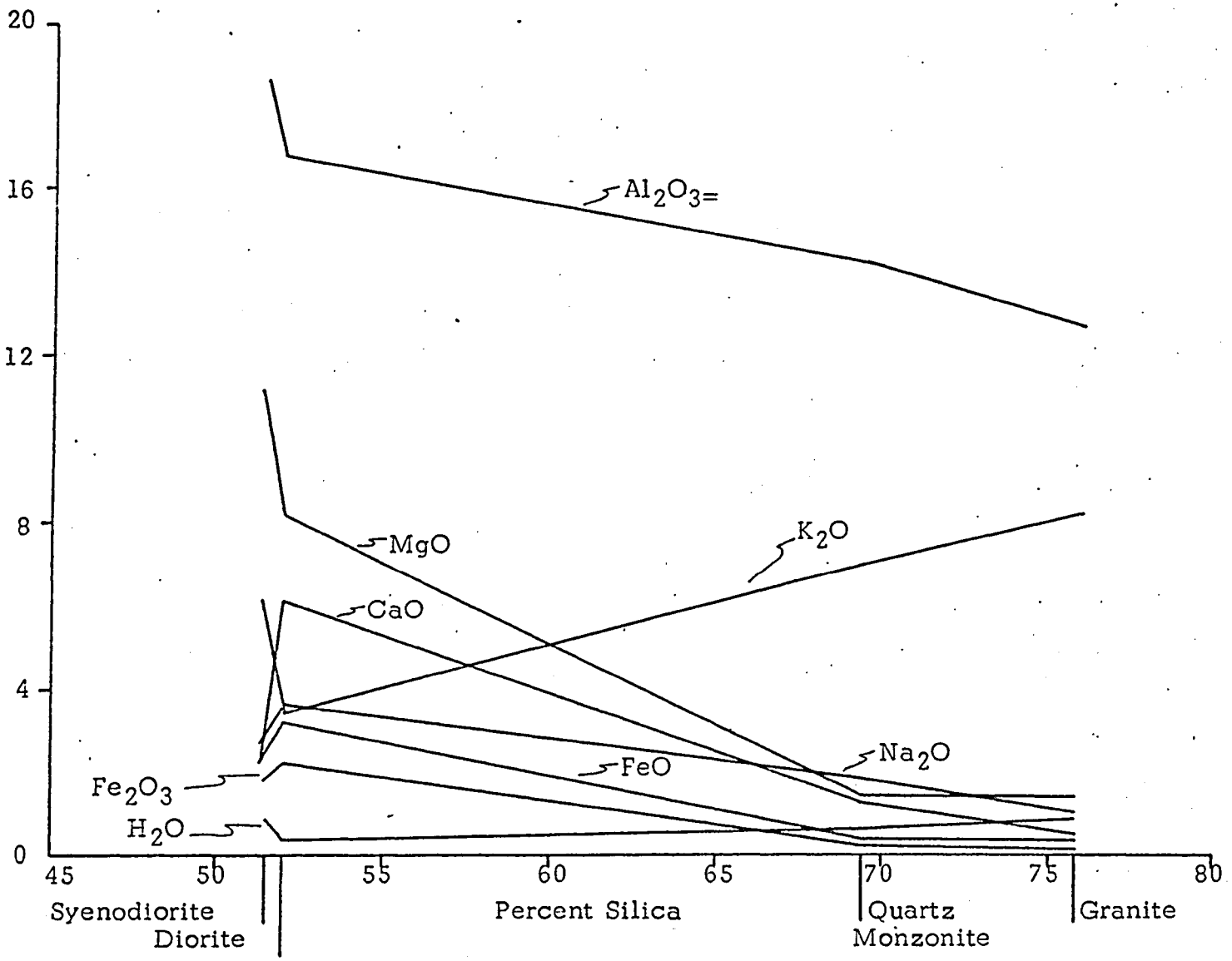
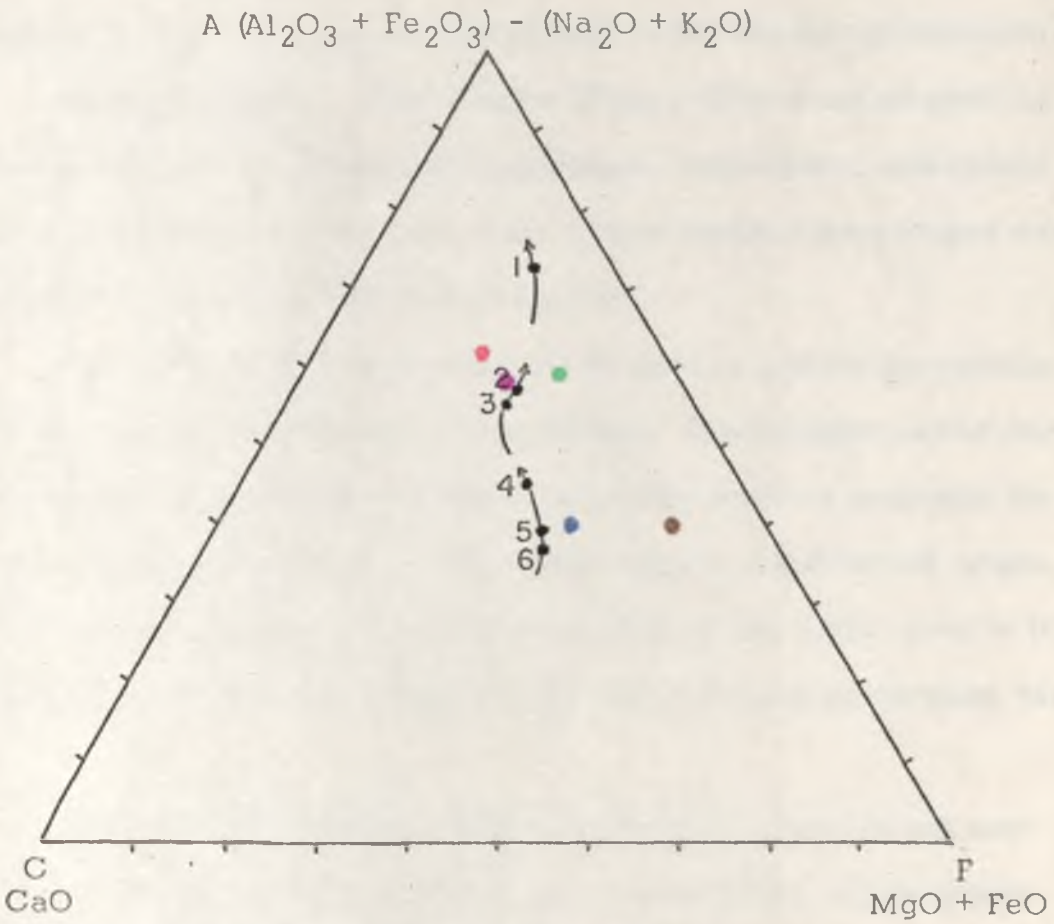


Figure 3. Harker Variation Diagram

some other means, perhaps by assimilation and metasomatic reactions between two or more rock units. As indicated on the diagram, there is a relatively smooth curve progressing from the granite through the quartz monzonite to the diorite. However, there is a sharp break in the curves between the diorite and the syenodiorite. There are not enough points to determine whether the entire sequence of diorite — granite fromed through a process of magmatic differentiation or by assimilation. However, because there is such a marked difference in the compositions of diorite and syenodiorite, it is possible that the syenodiorite may not have been the result of magmatic differentiation.

ACF Diagram. This diagram (Figure 4) compares the igneous rocks in the thesis area to Nockolds' (1954) chemical analysis of igneous rocks. The diagram was constructed by first calculating the chemical composition of a rock from the weighted percent of the minerals and then calculating A ($Al_2O_3 + Fe_2O_3$) - ($Na_2O + K_2O$), C (CaO), and F (MgO + FeO). The results were then plotted on the ternary diagram. This procedure was used to calculate the plot of the rocks in the thesis area as well as the average chemical composition of some igneous rocks as analyzed by Nockolds. The points representing the various rocks as plotted on the diagram reveal that all but one of the rocks in the thesis area conform relatively well to those igneous rocks as analyzed by Nockolds. The exception is the syenodiorite.

The syenodiorite in the thesis area differs from Nockolds' syenodiorite in that it contains a greater percentage of mafics. This is reflected in the larger percentage of MgO and FeO in the thesis syenodiorite as compared to Nockolds' syenodiorite. The thesis syenodiorite also



Nockolds' Rocks

1. Cal.-Alk. Granite
2. Quartz Monzonite
3. Granodiorite
4. Syenodiorite
5. Diorite
6. Gabbro

Thesis Rocks

- Granodiorite
- Granite
- Syenodiorite
- Quartz Monzonite
- Diorite

Figure 4. ACF Diagram Showing Nockolds' Averages as Compared to Similar Rock Types in the Patagonia Mountains

contains less plagioclase than the syenodiorite analyzed by Nockolds as reflected in the lower percentage of CaO in the thesis syenodiorite.

Modal Diagram. This diagram (Figure 5) was constructed by calculating the volume percent of plagioclase, orthoclase, and quartz in each thin section for each rock unit. These various percentages were then plotted as points on the ternary diagram.

The rocks in the thesis area which plot as granite lie outside the thermal valley of Tuttle and Bowen (1958). The triangle on the diagram indicates where Tuttle and Bowen's normal granites generally lie. It is possible that the granite in the thesis area had a different origin. The fact that the granite in the western portion of the thesis area is low in plagioclase may have something to do with it having an atypical history.

Although the quartz monzonite in the thesis area is not considered a quartz monzonite by Tuttle and Bowen (1958), since it lies outside their quartz monzonite field I assumed that if 33 to 67 percent of the total feldspar was plagioclase, the rock was a quartz monzonite (Moorhouse, 1959).

Field Evidence Relating to the Origin of the Igneous Rocks

In the central portion of the mapped area, the diorite and the syenodiorite are similar in both texture and composition. Both are medium to coarse grained and the only apparent differences are euhedral biotite crystals and a greater percentage of biotite and plagioclase in the diorite. These two rocks are generally difficult to distinguish in the field.

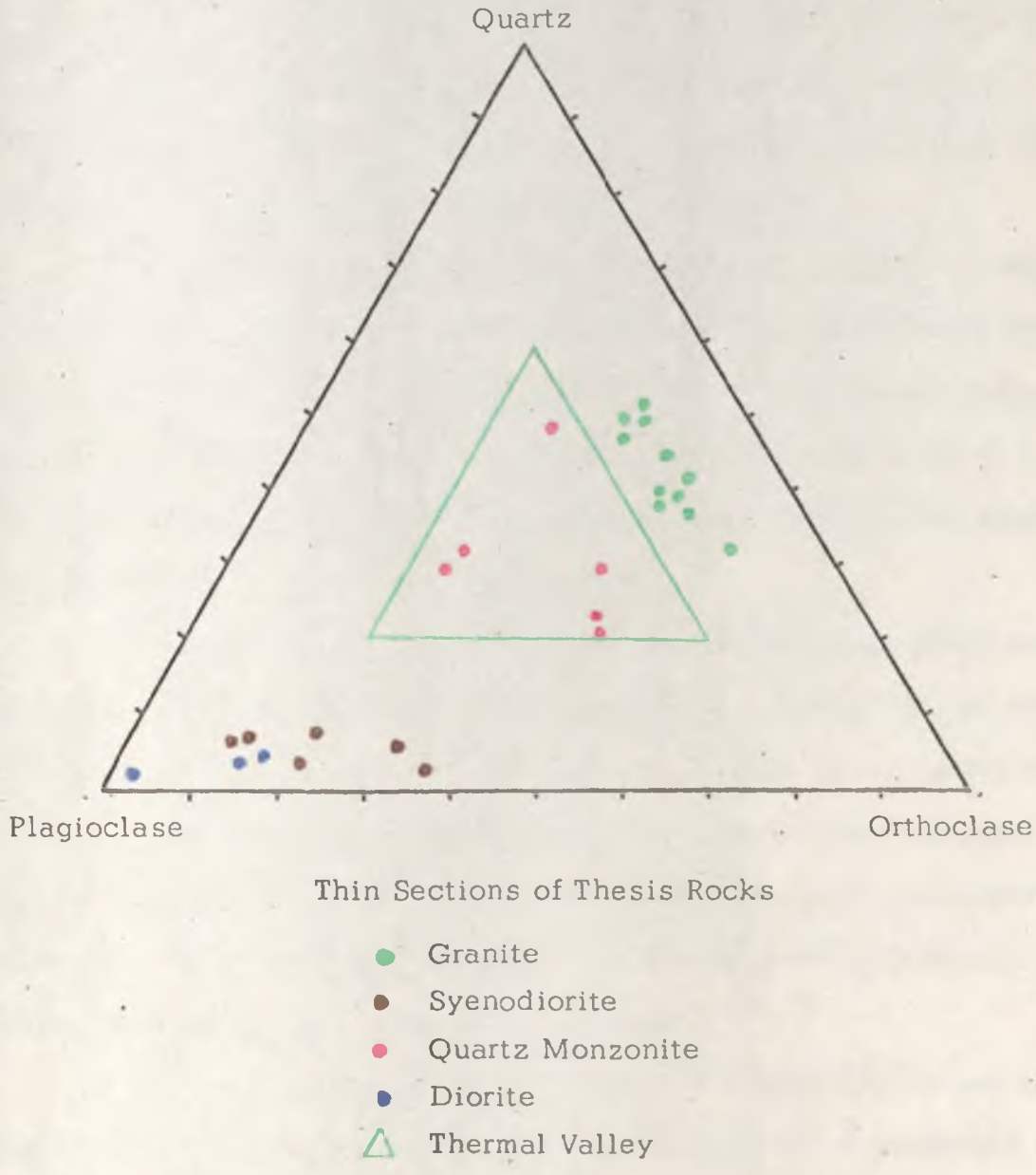


Figure 5. Diagram Showing Modal Percentages of Quartz, Plagioclase, and Orthoclase in Thin Sections of Thesis Rocks

In the syenodiorite, particularly along the edge of the syenodiorite-quartz monzonite contact, there are numerous orthoclase grains with gradational borders growing in the syenodiorite. These suggest that assimilation of the syenodiorite by the quartz monzonite has taken place along the syenodiorite-quartz monzonite contact.

The granite occurs in isolated patches and is generally very closely associated with the diorite and syenodiorite, particularly in the eastern portion of the area. It appears that the granite acts as a boundary between the quartz monzonite and the more basic rock units in the area and represents the residue of minimum melting components from the crystallization of the quartz monzonite.

Numerous diorite inclusions and quartz monzonite dikes leave little doubt that the quartz monzonite intruded the diorite. In the western portion of the area (Figure 2), there are some diorite dikes cutting the quartz monzonite showing that there may have been a later intrusive phase of the diorite, perhaps unrelated to the obviously earlier diorite which the quartz monzonite intruded. These diorite dikes present a problem which has not been resolved by the study.

The location of the contact between the syenodiorite and the quartz monzonite varies depending upon the amount of assimilation that has taken place. As this contact is approached, there is an increase in the grain size of the mafic minerals within the quartz monzonite but a decrease in their amounts. The syenodiorite, in general, becomes coarser grained near the quartz monzonite contact and the percentage of quartz increases while the percentage of mafics decreases.

The diorite, syenodiorite, and granite constitute approximately 30 percent of the rocks mapped in the thesis area. In order to determine the approximate chemical composition of the original rock into which the quartz monzonite intruded, I combined, in a weighted percent, the chemical composition of diorite, syenodiorite, and granite in the following proportions: diorite--20%; syenodiorite--60%; and granite--20%. These proportions represent an estimate of the percentage of each respective rock type constituting the 30 percent of the rocks mapped in the area as diorite, syenodiorite, and granite. By these calculations a rough estimate was determined for the chemical composition of the original rock. By correlating the chemical composition of the original rock with Nockolds' chemical analysis of igneous rocks, it was determined that the original rock was located chemically between a tonalite and an alkali syenite.

Interpretation

From data derived from the construction of the various diagrams above and from the field evidence cited, the following conclusions may be drawn. The quartz monzonite intruded a tonalite-alkali-syenite mass. A reaction between the quartz monzonite intrusion and the original rock produced the syenodiorite through a process of metasomatism and assimilation. This is supported by the ACF Diagram, the variable composition of the syenodiorite, and the metasomatic alteration within the syenodiorite. The residue which was left over was then concentrated and resulted in the formation of the diorite. It may well be that the original tonalite was transformed into the now-existing diorite through a process of assimilation by the quartz monzonite intrusion.

Although the diorite in the thesis area is similar to Nockolds' diorite, the syenodiorite in the thesis area is not similar to his syenodiorite because of the lack of CaO and also because it has too much MgO and FeO. The variation diagram shows that K_2O, Al_2O_3, and MgO were lacking in the diorite as compared to the syenodiorite. The lack of K_2O and Al_2O_3 would be expected as they are the low melting minerals of Bowen's reaction series. A high percentage of mafics in the syenodiorite accounts for the low percentage of MgO in the diorite. The large amount of CaO in the diorite as compared to the syenodiorite is accounted for by the great abundance of epidote in the diorite.

The granite represents the residue of minimum melting components from the quartz monzonite as the latter crystallized.

STRUCTURE

The Patagonia Mountains are a north-northwest trending mountain range. This direction is marked not only by the trend of the mountain range itself but is also manifested in a precipitous fault scarp along the axis of the range as well as numerous parallel faults and fractures in the thesis area. This north-northwest direction also corresponds to the trend of the front range fault located on the western side of the range and is the major structural feature in the thesis area (Figure 6, in pocket).

A second major structural trend is nearly normal to the north-northwest direction and is reflected in the trend of exposures of sedimentary and volcanic rocks in the southern part of the Patagonia Mountains. This northeast trend has been particularly important in localizing mineralization in the western part of therange.

Types and Distribution

In general, structural movement in the area has not been great. The major structural features in the thesis area are faults and fractures which are concentrated in the northern portion of the area where mineralization has been most intense. Shears are not pervasive in the thesis area but are intense in certain areas. The front range fault is the only fault of major significance in the area. Neither faults nor fractures display any preference with regard to rock types, which suggests that these structural features are not controlled by rock types.

The major structural trends in the thesis area, as indicated in Figure 7, are: N. 33° E., N. 43° E., N. 60° E., and N. 18° W., N. 38° W., and N. 58° W. The majority of the fractures recorded strike in a northeasterly direction and dip steeply to the south. There are three prominent northeast-striking fracture trends and three prominent northwest-striking fracture trends. Although its magnitude is not revealed in Figure 7, the major front range fault is represented by the N. 18° W. trend.

Structural Patterns

The major structure in the thesis area is the front range fault. The trace of this fault extends from the Tres de Mayo group to beyond the southern limit of the mapped area. This fault zone varies in strike from N. 10° W. to N. 25° W. and varies in width from 100 feet to 400 feet. This structure is revealed primarily through the interpretation of aerial photographs (Figure 8), but it is also recognizable in the field. Although quite distinct in the southern portion of the area where there are fewer structures and a more uniform rock type, this front range fault becomes obscured by a complex mixture of rock types and intersecting structures at its northern extremity.

The fault is readily distinguished both on aerial photographs and on the ground by distinct changes in topography and drainage patterns. To the east of the fault the topography is more rugged and the ground is more highly dissected. To the west are small, gently sloping hills of predominantly quartz monzonite.

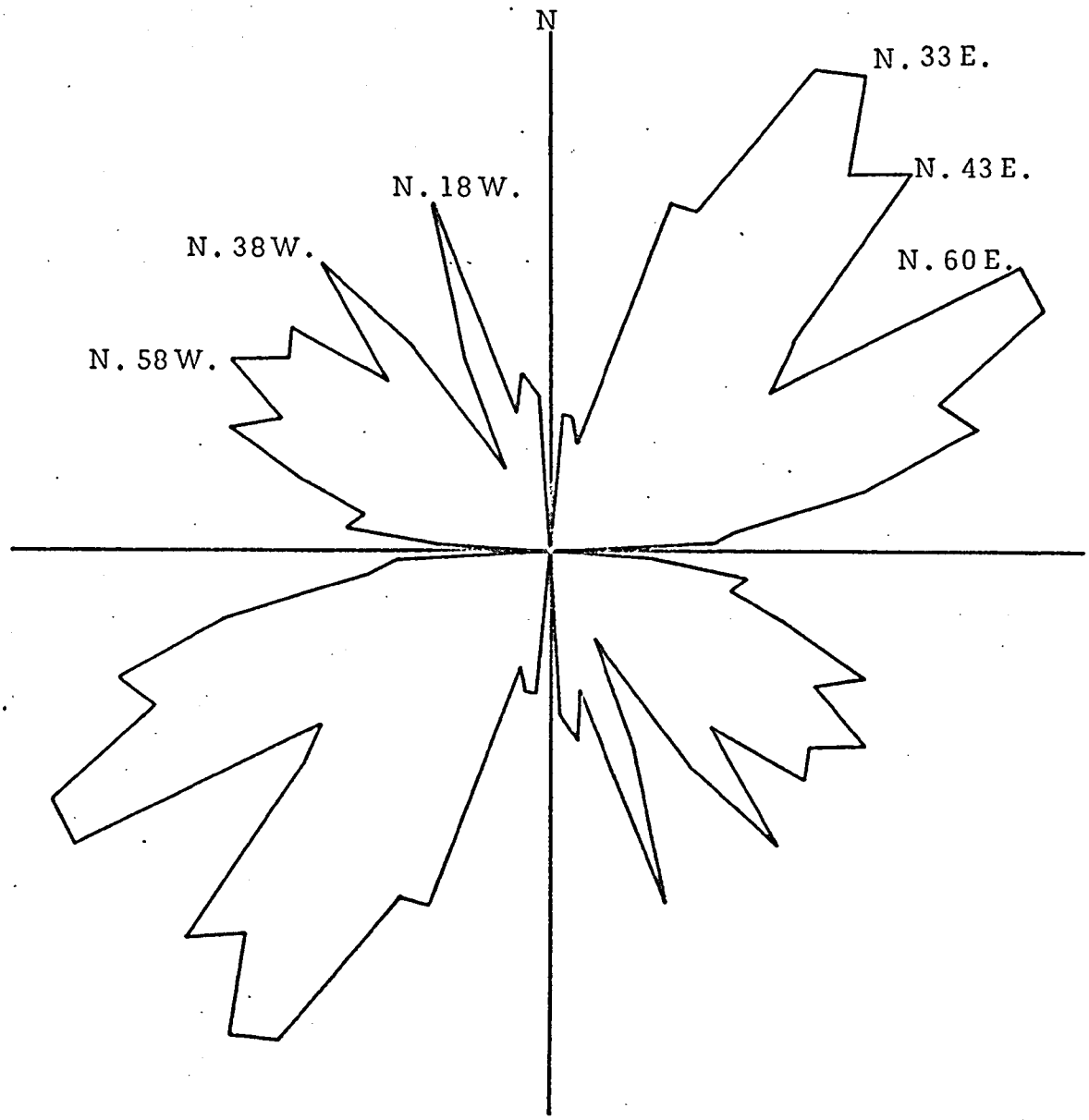


Figure 7. Rose Diagram Showing All Fractures in Thesis Area

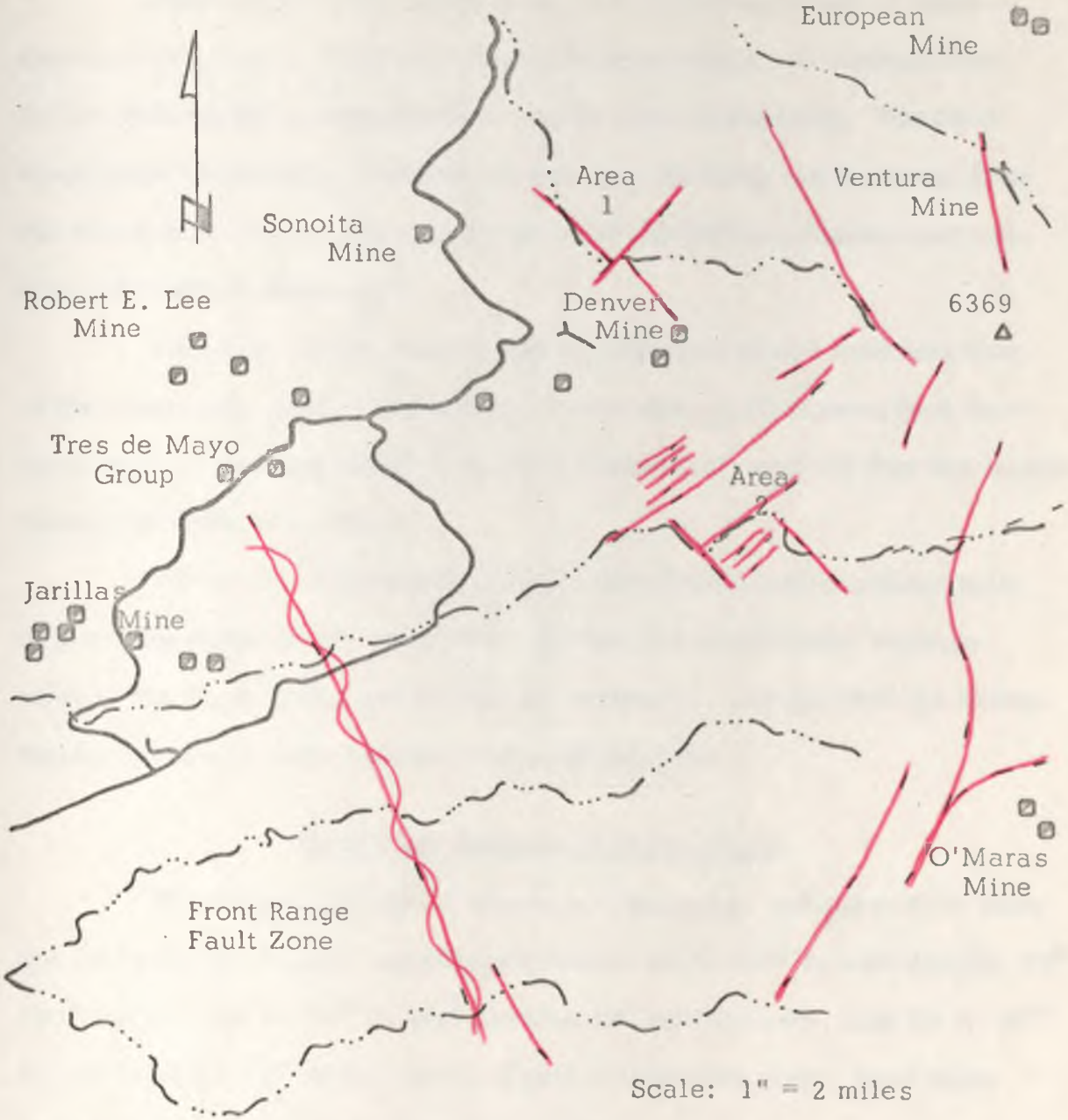


Figure 8. Sketch Map Showing Structural Trends from Aerial Photographs, Patagonia Mountains, Arizona

Although the front range fault is not distinguished by differences in rock types, field evidence indicates that it is distinguished by the differences in structures on either side of the fault. The front range fault serves as a partition by not only dividing the flatlands from the mountains, but by also acting as a divider between barren and mineralized fracture directions.

Figure 9, which records barren and mineralized fractures east of the front range fault, indicates: (1) that almost all mineralized fractures east of the front range fault strike northeast, and (2) that the barren fracture maxima are diffuse.

Figure 10, showing the barren and mineralized fractures west of the front range fault, indicates: (1) that the mineralized fractures west of the fault strike predominantly northwest, and (2) that the barren fractures show a well-defined northeast maximum.

Origin and Movement of Structures

The structural contour diagram, Figure 11, indicates that there are three barren maxima striking northeast: (1) N. 35° E. and dipping 54° to the north, (2) N. 35° E. and dipping 68° to the south, and (3) N. 55° E. and dipping 65° to the south. There is also one poorly developed barren maximum in the northwest direction.

With regard to the mineralized fractures (Figure 12), there is one well-developed maximum striking northeast, dipping south, and one moderately developed maximum striking northeast and dipping north. It is interesting to note that the first mineralized maximum mentioned above

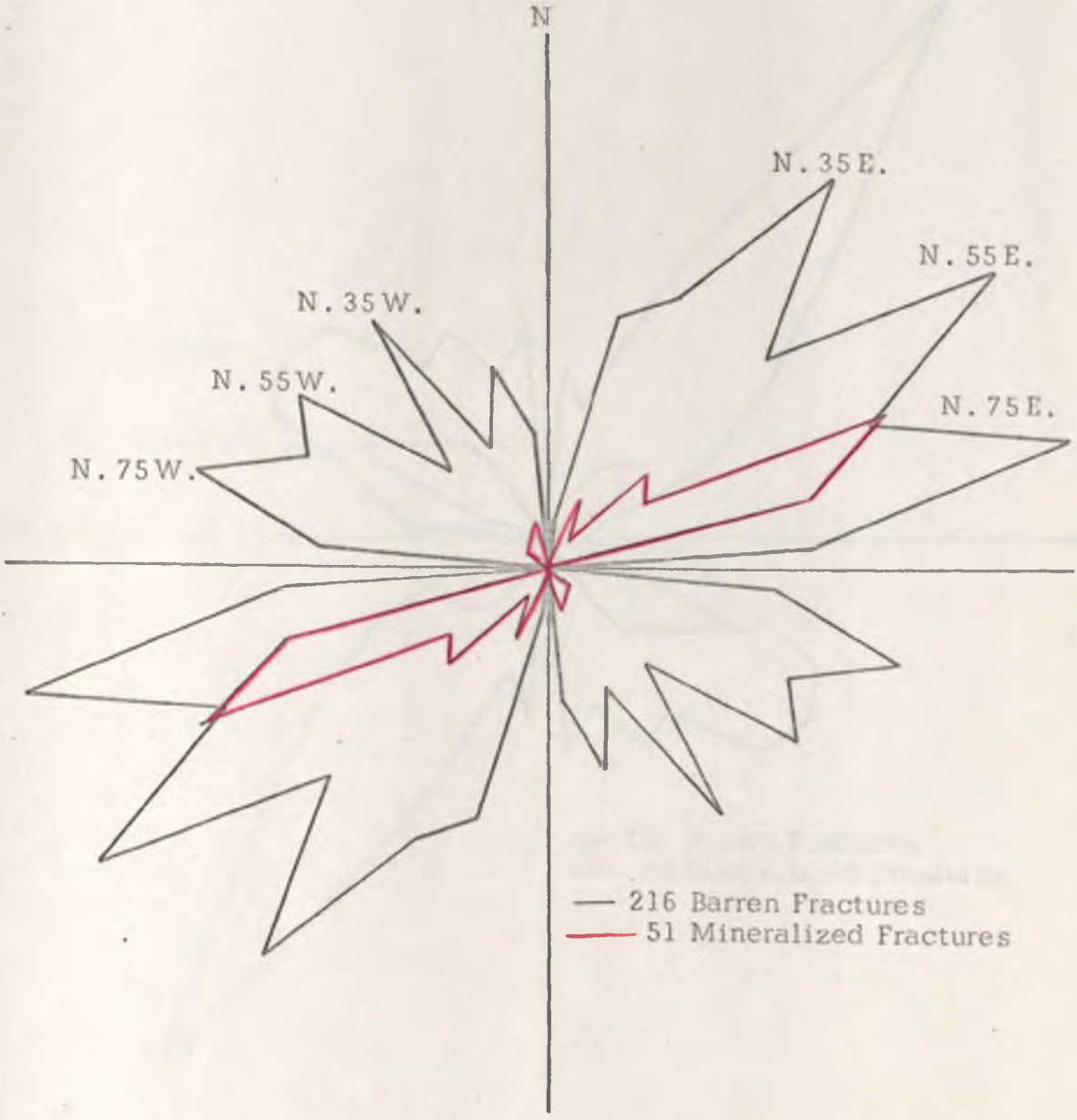


Figure 9. Rose Diagram Showing Barren and Mineralized Fractures East of the Front Range Fault

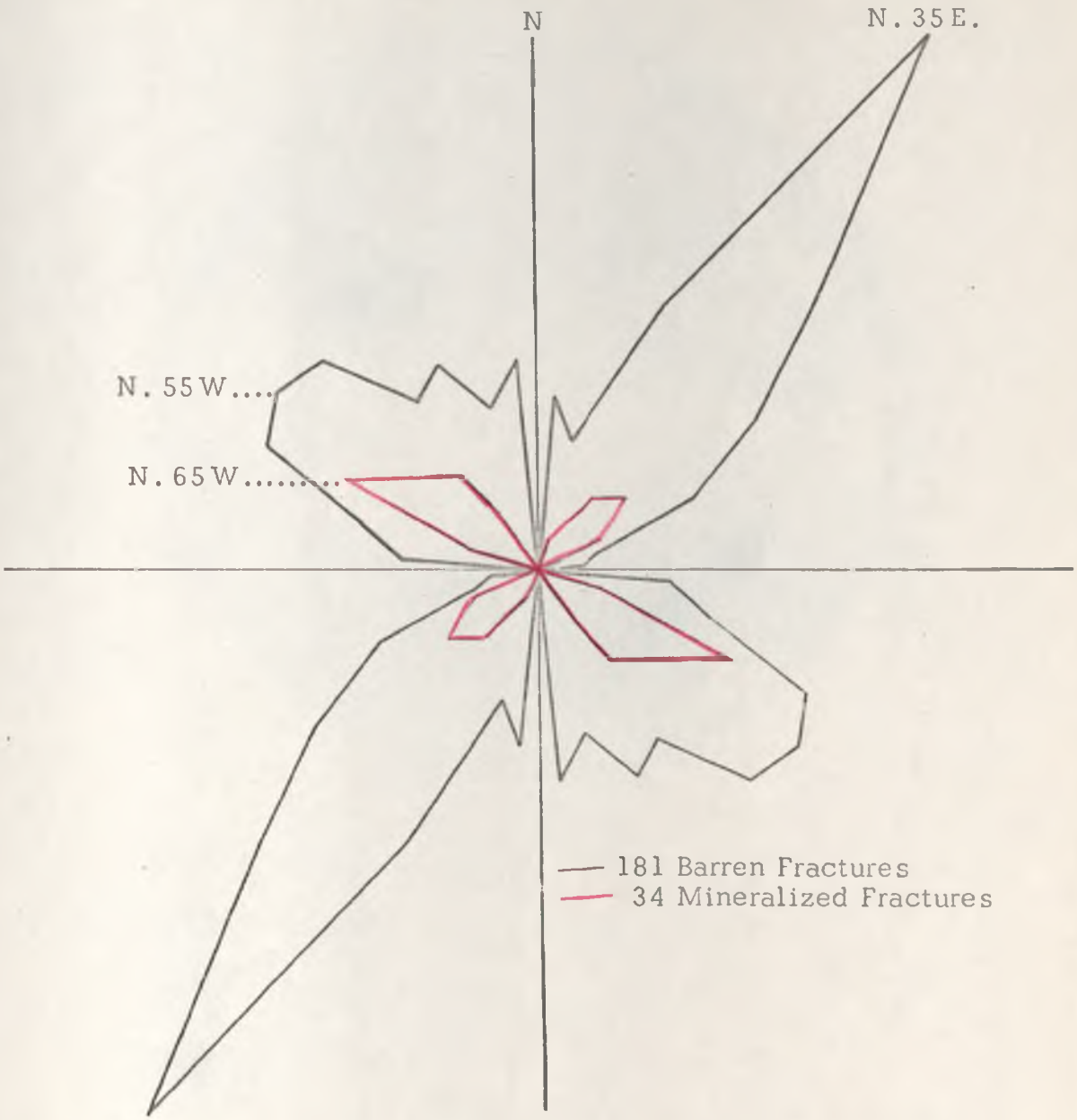


Figure 10. Rose Diagram Showing Barren and Mineralized Fractures West of the Front Range Fault

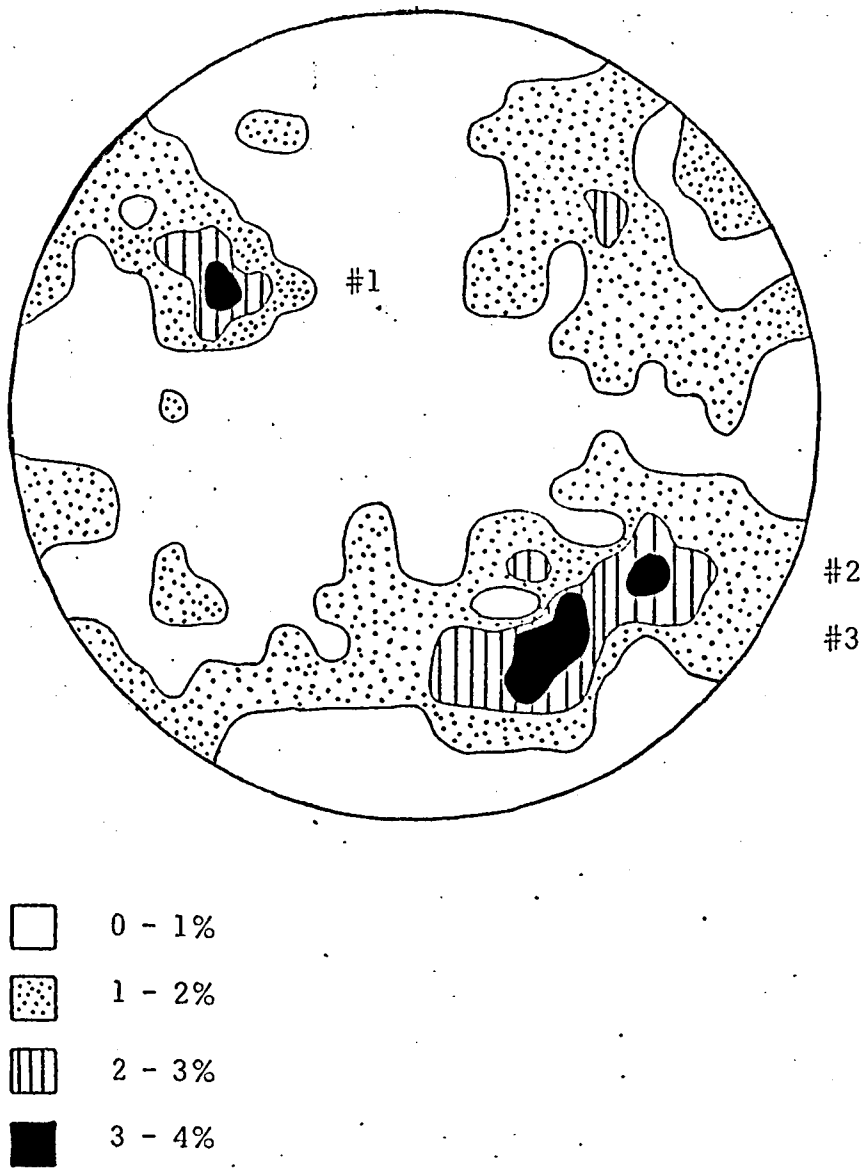
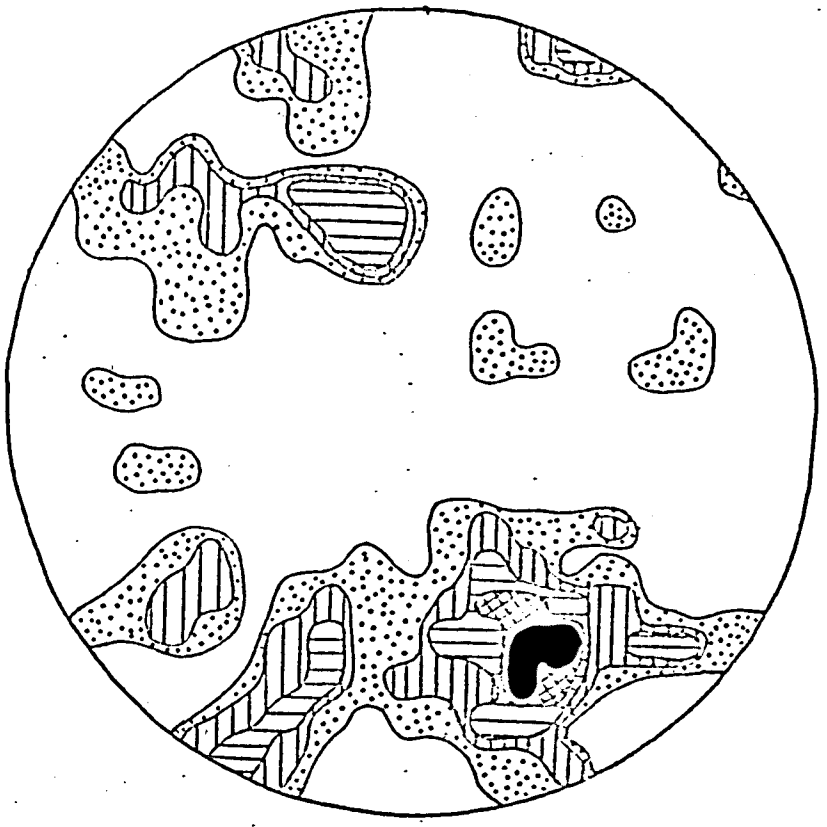


Figure 11. Contour Diagram Showing Barren Fractures in Thesis Area, Patagonia Mountains, Arizona



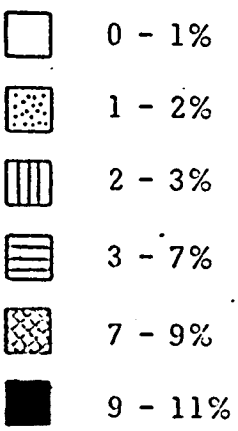


Figure 12. Contour Diagram Showing Mineralized Fractures in Thesis Area, Patagonia Mountains, Arizona

corresponds with the N. 55° E. trending, south-dipping barren maximum.

The strain ellipsoid concept was used in an attempt to formulate a hypothesis explaining how these fracture maxima developed. According to Billings (1954), shear fractures may develop in the strain ellipsoid as a result of compression, tension, or couple movement. The angle that is bisected by the compressive force is always less than 90 degrees and is usually around 60 degrees; that is, the angle between the compressive force and the shear fractures is about 30 degrees.

The maximum acute angle between each of the three barren maxima was calculated with the following results:

A. Maximum acute angle between #1 and #2 is 58 degrees,

B. Maximum acute angle between #1 and #3 is 61 degrees,

C. Maximum acute angle between #2 and #3 is 20 degrees.

Although C does not fit into the strain ellipsoid concept, A and B do conform to this concept. It is my opinion that from the above determinations the majority of the fractures in the thesis area are shear directions formed primarily through vertical compression. Analysis of the intersection of the fracture maxima #1 and #3 indicate that the compressional force (the bisector of the maximum acute angle), probably had a steep northeast inclination, and was probably of a vertical nature.

The time at which these fractures developed is not known precisely, but it was probably during the Laramide age. It is my opinion that the fractures are related in time to the Laramide intrusion in the central portion of the mountain range and that the vertical compressive forces accompanying the intrusion helped produce these fractures.

Although vertical tectonics appear to have played a role in the development of the structures in this area, there is also evidence of some strike-slip movement. The structural map derived from aerial photographic interpretation (Figure 8) clearly indicates the possibility of strike-slip movement. Just north of the Denver mine (Figure 8, Area 1), a fracture nearly parallel to the front range fault has been offset by a northeast striking fracture. The movement in this case appears to have been left lateral with no substantial evidence for vertical movement.

In an area approximately two miles southeast of the Denver mine (Figure 8, Area 2), there appears to have been strike-slipe movement in both the northeast and northwest directions. The movement in this case appears to have been left lateral in the northeast direction and right lateral in the northwest direction. Further evidence for strike-slip movement in this area is the strong amount of shearing in the outcrops, particularly in the northeast direction.

Although movement of a strike-slip nature is evident in both these areas, it is difficult to determine if there has been any vertical component to this movement.

The evidence cited for strike-slip movement involves rocks located approximately three miles from the front range fault zone. It is perhaps possible to assume that within the 100-400 foot front range fault zone movement has not only been vertical but also of a strike-slip nature. Evidence within this zone for strike-slip movement has been obscured by the complexity of rock types and structure in the area. Perhaps the complexity itself is evidence for multidirectional movement

within the zone. Since the Patagonia Mountains are situated in the Basin and Range province, it may very well be that the front range fault is associated with the vertical tectonics accompanying Basin and Range block faulting and mountain building.

It appears that vertical tectonics played the major role and strike-slip movement a secondary role in the structural pattern developed in the thesis area.

ECONOMIC GEOLOGY

General History of the Area

The thesis area is situated in the Palmetto Mining district, Pima County, Arizona, which extends from Sonoita Creek south to Paloma Canyon and which is bounded by the crest of the Patagonia range to the east and the Estrada Ranch to the west.

The mining history of the area dates back to the turn of the century when numerous prospectors exploited the rich lead-silver ores associated with diorite dikes and banded quartz veins in the quartz monzonite and the larger, more disseminated copper mineralization associated with shear zones in the granite porphyry. In the thesis area the lead-silver deposits are primarily located in the west-central portion of the area while the disseminated copper deposits are situated in the southeast portion of the mountains.

General Mineralization of the Area

Within the mapped area, the lead-silver ores are closely associated with northwest-striking, south-dipping fractures, intrusive diorite dikes, and quartz veins either in the quartz monzonite or near the contacts of the quartz monzonite with the diorite complex. These deposits consist of argentiferous galena, cerussite, and minor amounts of chalcopyrite, malachite, azurite, and gold. The major gangue minerals are quartz and psilomelane. These deposits postdate the quartz monzonite intrusion and are most likely associated with the granodiorite intrusion

in the central portion of the Patagonia Mountains. Figure 13 shows the general metal distribution in the mines around the granodiorite intrusion and indicates symmetrical zoning of silver deposits around the intrusion. A rather distinctive zoning pattern reveals copper at the core of the granodiorite intrusion, copper-silver distributed in the intermediate zone, and silver concentrated in the outer fringer.

With this type of zoning it appears that the silver-lead mineralization in the area is closely associated with the intrusion of the Laramide granodiorite. This intrusion may have not only produced the vertical compression which accounted for the various fracture directions developed during compression, but may also have been the source of the fluids which later mineralized the northeast and northwest fractures when compressional forces were relaxed.

At the north end of the map shown in Figure 13, the zoning symmetry is lost as an irregular protrusion extends to the northeast. Within this extended protrusion lies a central zone of copper mineralization. This zone appears to pinch out to the northeast. This protrusion may be explained by either a north-northeast fault occurring just south of the Flux mine, or by the Laramide intrusion plunging to the north-northeast. In view of the fact that there is no evidence in the field or on aerial photographs indicating the presence of a fault in this area, the best explanation for the northeastward extension of the mineralized zone is that the top of the Laramide intrusion plunges to the north-northeast.

Disseminated copper mineralization occurs in the intrusion. Pyrite and chalcopyrite are weakly disseminated throughout the granodiorite and are concentrated along northeast and east-northeast altered

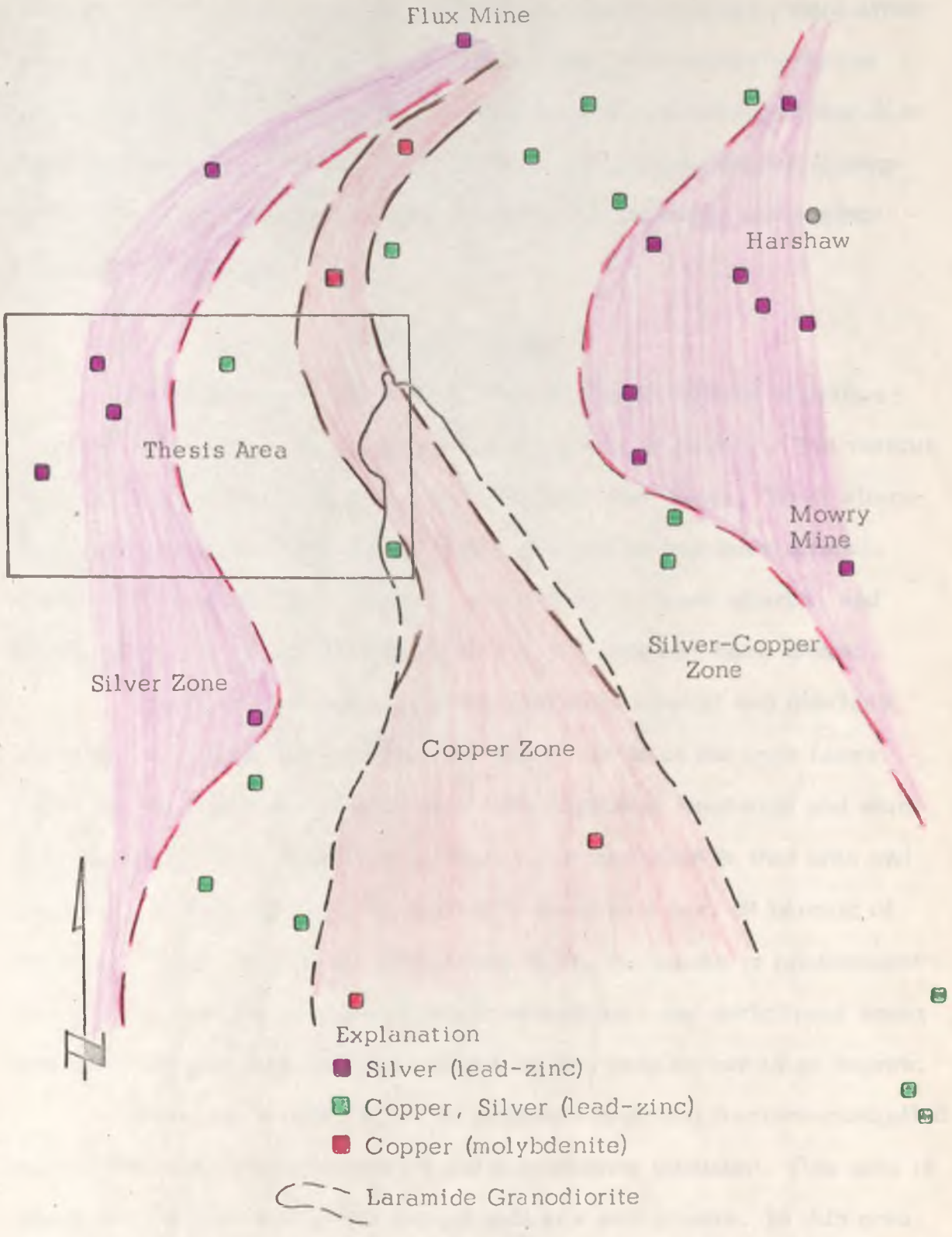


Figure 13. Sketch Map Showing Metal Distribution in Mines Around the Laramide Intrusion, Patagonia Mountains, Arizona

fracture zones. These northeast and east-northeast fractures were either formed or reopened along preexisting structural weaknesses after the emplacement of the granodiorite. It is thought that ascending mineralizing solutions deposited various sulfides in these fractures and impregnated the surrounding country rock with quartz, sericite, and a minor amount of tourmaline.

Areal Alteration

The three major types of alteration present include silicification, sericitization, and epidotization (Figure 6, in pocket). The various degrees of alteration include weak, moderate, and strong. Weak alteration indicates that less than 10 percent of the rock has been altered, moderate alteration, 10-50 percent of the rock has been altered, and strong alteration, more than 50 percent of the rock has been altered.

Quartz is the most pervasive alteration mineral and overlaps sericite and epidote in both time and space. West of the front range fault, quartz is primarily associated with northwest fracturing and vein mineralization. It is exceedingly strong and pervasive in this area and along with the epidote will occasionally constitute over 50 percent of the rock. To the east of the front range fault, the quartz is predominantly associated with northeast mineralized fractures and sericitized zones and does not permeate the surrounding country rock to any large degree.

There are several areas of moderate to strong fracture-controlled quartz alteration associated with the granodiorite intrusion. One area is along the northern contact of the granodiorite and granite. In this area, northeast and east-northeast striking altered zones are moderately to

strongly silicified. Another region of intense quartz alteration is in the vicinity of the O'Maras mine, and a third locality is in association with the brecciated zones in the granodiorite.

Although it is not as widely distributed as the quartz, the epidote alteration is also very strong in the mineralized area west of the front range fault. The epidote is pervasive throughout this area but is primarily concentrated along quartz monzonite-diorite contacts and along the contacts of the diorite dikes with the country rock. West of the front range fault, the most pervasive area of epidote alteration appears to form a core around which several of the mines are located. Generally, the greatest number of mineralized fractures occurs where there is a decrease in the intensity of epidote alteration. It appears that the epidote has healed many of the fractures and is thus perhaps an unfavorable indicator of ore.

The epidote alteration is considerably less pervasive to the east of the front range fault. This might be explained by: (1) the fault acted as a barrier to solutions penetrating to the east, (2) the northeast fractures and channelways were insufficiently open to permit penetration of the solutions, or (3) the chemical environment of the country rock was incompatible with intense epidotization. It appears that the first two can be eliminated because they would be in contradiction to the movement of mineralizing fluids which accounted for the numerous northeast veins in this area.

It appears that when the diorite is in direct association with the quartz monzonite, there is pervasive epidote alteriation, but when it is in association with the syenodiorite intense epidote is lacking. I

believe that the chemical environment of the surrounding rock units accounts for the acceptance or rejection of CaO and the intense epidote. On the east side of the front range fault where there is little diorite, there is also little intense epidotization. However, on the west side of the front range fault, there is a greater amount of diorite and also a greater amount of intense epidotization. Intense epidotization is associated with the diorite but not with the other rock units.

Areas of strong sericite alteration are primarily confined to within the granodiorite mass, particularly near its northern contact with the granite. Here the sericite alteration is closely associated with the northeast and east-northeast mineralized fractures and forms altered zones several hundred feet wide. These sericitized zones trend N. 60° E. in the granite and then shift to a nearly east-west direction as they cross the granodiorite contact. These zones, which vary in width from 100 to 400 feet, contain moderate to strong east-northeast and east-west faulting and fracturing. Sericite is also common in the several brecciated zones within the granodiorite.

Weak to moderate sericite alteration is present in the northwest mineralized fracture zones in the quartz monzonite and in the diorite-syenodiorite complex. In these zones, the sericite alteration is generally associated with abundant quartz and is confined to the immediate fracture zone.

In general, the alteration of the biotite to chlorite in the diorite-syenodiorite complex and in the granodiorite appears to be of little significance with regard to mineralization. Chlorite is disseminated within the syenodiorite and does not necessarily accompany the northeast

mineralized fractures. Minor chloritization occurs in both the diorite and granodiorite. Within the diorite, chloritization is associated with epidotization of the diorite dikes, while in the granodiorite chlorite is well disseminated.

The presence of tourmaline is generally confined to the brecciated areas within the granodiorite where it is an alteration product as well as a cementing agent. There are a few occurrences of tourmaline in fractures within the quartz monzonite, but these occurrences are usually situated close to the quartz monzonite-granodiorite contacts.

In conjunction with the metal distribution around the Laramide intrusion (Figure 13), there is also a general zoning of alteration. As the Laramide intrusion is approached, there is an increased amount of sericite and tourmaline alteration associated with the copper mineralization and a decrease in epidote.

Mines and Prospects

Sonoita Mine

The Sonoita mine is located at the north-central edge of the mapped area. It is at an elevation of approximately 4,480 feet and consists of a single shaft inclined 75° to the south. The mine is situated on the contact between the quartz monzonite and the diorite-syenodiorite complex.

A vertical north-northeast-striking vein coincident with the contact is intersected by a northwest-striking fracture in the vicinity of the shaft. Mineralization is concentrated at this intersection and consists primarily of pyrite, chalcopyrite, malachite, azurite, and minor

amounts of silver and gold. Quartz and psilomelane constitute the gangue which forms a gouge in the contact zone. The alteration within the contact zone is generally weak, but there is moderate epidote and chlorite in the diorite and spotty sericite in the quartz monzonite.

Recent (1966) operations have attempted to locate a faulted portion of the quartz vein at a depth of 125 feet.

Robert E. Lee Mine

This mine is situated about one mile southwest of the Sonoita mine and consists of three shafts sunk on a northwest-striking and south-dipping vein. These shafts are located in both the quartz monzonite and the diorite complex. Several northwest-striking diorite dikes cut the country rock in this area. If extended, the front range fault would bisect this area.

The mineralization occurs in two primary veins, one striking N. 65° W. and dipping 85° S., and the other striking N. 35° W. Approximately 300 feet apart, these veins vary in width from 2 to 5 feet. The mineralization is closely associated with the intrusive diorite dikes, and the alteration products include quartz and epidote. The principal ore minerals include argentiferous galena, spotty pyrite and chalcopyrite, and minor amounts of gold and silver.

The Robert E. Lee mine is located at the fringe of the strong quartz and epidote alteration. Near the diorite-quartz monzonite contact, both the diorite and the quartz monzonite have been weakly chloritized and moderately epidotized. The veins occur in an area of intense shearing and fracturing and are moderately altered with quartz and epidote and weakly altered with sericite.

Tres de Mayo Group

Three shafts located 1,500 to 2,000 feet south of the Robert E. Lee mine constitute the Tres de Mayo group. These shafts are situated in the quartz monzonite between the diorite and syenodiorite complex. The front range fault extends through this area, and the mineralization in this group is controlled in part by N. 60° E. fractures and in part by several northwest-trending diorite dikes.

Alteration along the mineralized veins consists of strong silicification and moderate sericitization. Some chlorite occurs in the diorite dikes.

Mineralization consists of silver, lead, and copper, and the gangue includes quartz and psilomelane.

Jarillas Mine

The Jarillas mine is situated approximately 3,500 feet southwest of the Tres de Mayo group. It consists of four vertical shafts averaging a depth of 90 feet sunk on a N. 65° E. quartz fissure vein which dips steeply to the south and is approximately two feet in width. This vein parallels an intrusive diorite dike in the quartz monzonite. It appears in this case that the diorite dike controls the mineralization. This occurrence is in contrast to the northwest fracture direction which controls the mineralization of the mines described earlier.

The vein at the Jarillas mine consists primarily of quartz, limonite, psilomelane, azurite, and malachite, with the ore being a well-banded quartz containing copper and lead sulfides and a minor amount of silver.

Denver Mine

This mine is located about 2,000 feet southeast of the Sonoita mine and consists of one adit and several shafts. The rocks of this area are weakly altered, coarse-grained quartz monzonite and syenodiorite, and unaltered fine-grained granite. Moderate to strong quartz and sericite alteration is confined to the mineralized fracture zones through which the adit is driven.

The Denver adit is several hundred feet in length and trends N. 60° W. on the quartz monzonite-syenodiorite contact. Several N. 65° E. trending mineralized fracture zones, dipping south and varying from 8 inches to 2 feet in width, are cut by the main Denver adit. These zones are filled qith quartz and psilomelane, and with minor to moderate amounts of pyrite, chalcopyrite, sphalerite, and galena.

Two shafts located to the east of this adit are situated in the quartz monzonite and on the granite-syenodiorite contact. These are located on a N. 47° E. vein structure which dips to the south. This vein consists of a one to two foot mineralized zone containing quartz, pyrite, chalcopyrite, and minor amounts of galena. Alteration is generally moderate and in the form of quartz and sericite.

Other adits and shafts in the vicinity of the Denver mine are located on northeast mineralized fractures and are similar to those just described in their alteration and mineralization.

O'Maras Mine

The O'Maras mine is located in the granodiorite intrusion near the quartz monzonite contact in the southeast portion of the mapped

area. It is composed of several shafts with rather extensive underground workings. The main shaft is vertical and is located 250 feet southeast of a second shaft which is at a higher elevation and is inclined 70° to the southeast. This inclined shaft follows the mineralized vein which strikes N. 70° E. and dips between 70°-85° south. The country rock is a medium-grained granodiorite, but the mine and vein are closely associated with the quartz monzonite contact which lies to the west. The quartz monzonite is a medium- to coarse-grained rock which is relatively fresh except in the mineralized area. Here both the quartz monzonite and the granodiorite are moderately silicified and sericitized. Fibrous black tourmaline is intergrown with quartz in this mineralized area.

Mineralization in the vein consists of banded quartz with pyrite, chalcopyrite, and bornite. Minor amounts of these sulfides are disseminated throughout the country rock in the vicinity of the mine.

Other Areas of Mineralization

Along the zone of the front range fault, there are numerous prospect pits and mineralized fractures. This zone is several hundred feet in width and is composed of complex interrelated rock units as well as intersecting structures. Within this front range fault zone the mineralized fractures generally strike north-northwest on the west side of the fault and northeast on the east side of the fault.

Mineralized veins on either side of this fault vary from 1/8 inch to 12 feet in width. They are imilar to the mineralized fractures found in the various mines in this area. The veins may diverge from the

normal northeast and northwest directions and parallel either contacts between rock units or the basic dikes. The veins are generally moderately to strongly silicified. Moderate sericitization and chloritization of the diorite and bleaching of the country rock also accompany the mineralization.

The mineralization in these veins usually consists of copper and iron sulfides in massive quartz and various iron and manganese oxides.

Breccia

There are several small breccia structures within the granodiorite. The largest forms a small knob located in the approximate center of the granodiorite mass and as seen from the air has a U-shaped appearance. It is about 800 feet in length and 400 feet in width. Fragments are generally angular and vary in size from less than an inch to several feet. Some of the fragments exhibit partially rounded edges and reveal crude evidence of flow structure.

The breccia is highly silicified and sericitized and carries minor tourmaline. Massive pegmatitic quartz in the breccia exhibit various degrees of vugginess. The greatest percentage of vugs appears along the northern contact of the structure and occurs in the areas of coarse sericite and abundant sulfides.

Two rock samples were taken from the strongly altered and mineralized zone within this breccia structure. These samples were analyzed colorimetrically for total copper and molybdenum with the following results: Sample 1, 65 ppm Cu and 6 ppm Mo; Sample 2, 25 ppm Cu and 11 ppm Mo.

Other smaller breccia structures in the area reflect strong silicification and sericitization and contain varying amounts of tourmaline. Quartz vugs are generally sparse in these smaller structures. These breccia structures are probably caused by collapse as a consequence of magma withdrawal and reaction with residual liquids in the magma.

Mineralization within these breccias is confined to disseminated pyrite and traces of chalcopyrite and molybdenite.

Control of Mineralization

Mineralization in the thesis area is structurally controlled. The majority of the mineralization consists of veins and filled fractures, and is structurally controlled by northeast and northwest striking fractures as indicated on Figure 9 and 10. To the east of the front range fault, there is a strong N. 65° E. mineralized direction but no strong mineralized direction to the northwest. However, west of the front range fault, the preferred mineralized direction is N. 65° W. The northeast direction on this side of the fault is only moderately mineralized.

Figure 12 shows a well-developed mineralized maximum striking northeast and a moderately developed maximum striking northwest. A poorly defined maximum strikes northwest. These mineralized fractures are shears resulting from vertical compression. Owing to the fact that there is greater mineralization in the northeast fractures, it follows that these fractures were opened to a greater degree than the northwest fractures during relaxation of the vertical compression.

Origin of Mineralization

Mineralization in the diorite and syenodiorite consists of lead-silver veins with minor amounts of copper, gold, and molybdenu. The zoning, which has been discussed earlier (Figure 13), strongly suggests that these lead-silver veins were derived from the Laramide granodiorite intrusion. This intrusion was probably responsible not only for reopening the northeast and northwest shear directions but was also responsible for the fluids which later mineralized these shear directions.

The mineralization within the granodiorite and the associated breccia structures is characterized by the dissemination of copper and minor amounts of molybdenum. This mineralization owes its origin to the granodiorite in which it occurs.

Economic Potential

The numerous lead-silver veins located in the western portion of the thesis area are highly saturated with manganese and, as suggested by Hewett (1964), these manganese-stained veins may converge in depth to yield a higher grade of silver ore. The black manganese stain may indicate a transitional zone between molybdenite and silver veins with increased depth. Although the above is a possibility, it does not seem likely as silver mineralization usually decreases with increasing depth.

In the eastern portion of the area, it does not appear that the disseminated copper and molybdenum within the granodiorite has a great deal of economic potential. It appears that the mineralization in this area is too highly disseminated. The minor amount of drilling that has taken place in this area has not been very rewarding to date.

The author feels that the breccia structures may perhaps offer some economic potential. These should perhaps be drilled as there is always the possibility that their grade of ore will increase with depth.

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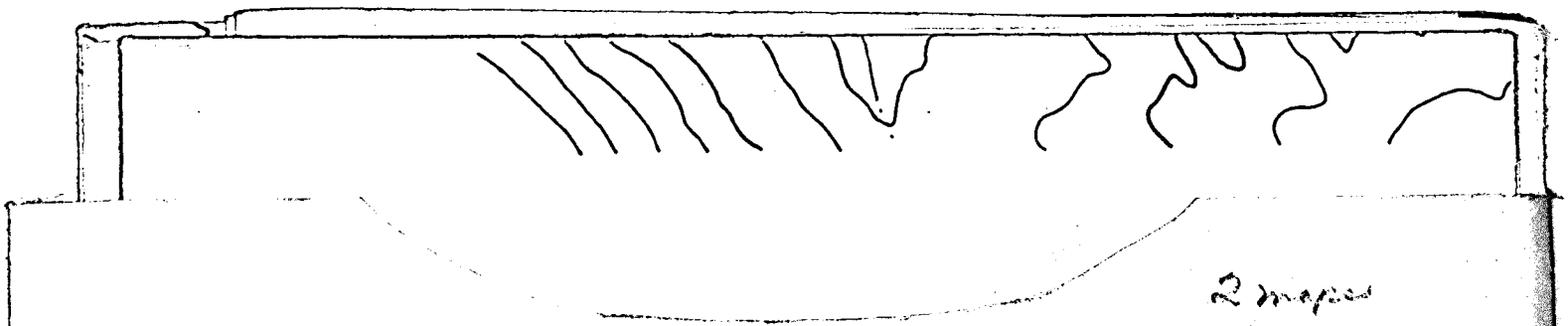

2 maps

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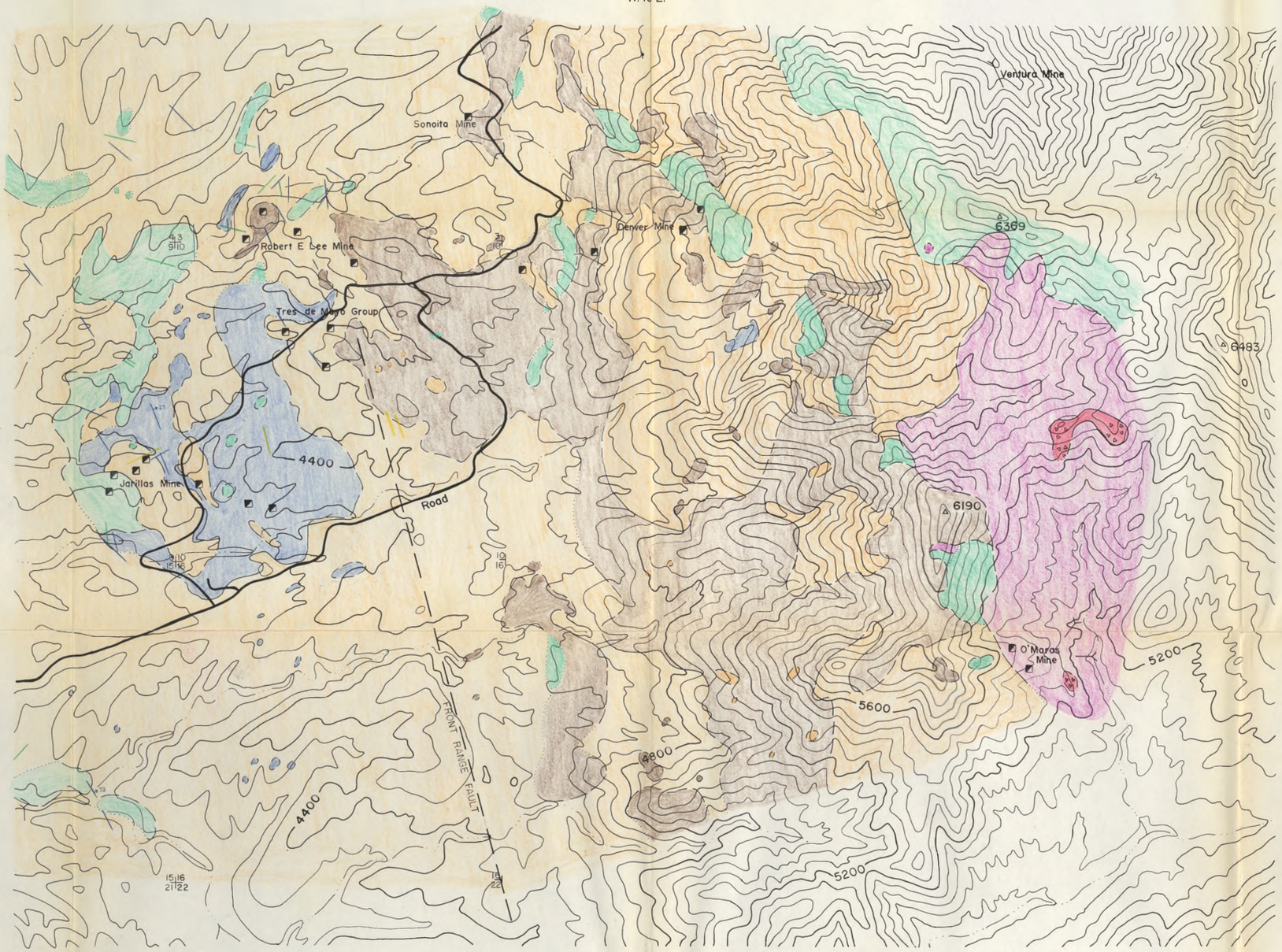

EXPLANATION

ROCKS — AGE

- Granodiorite — Laramide
- Granite — Unknown
- Syenodiorite — Unknown
- Quartz Monzonite — Unknown
- Diorite — Unknown
- Breccia

Dikes

- Quartz
- Diorite
- Aplite (granite)

CONTACTS

- Definite Contact
- Approximate Contact
- Inferred Contact

FIGURE 2

GEOLOGIC MAP OF THE WEST CENTRAL PORTION OF THE PATAGONIA MOUNTAINS SANTA CRUZ COUNTY, ARIZONA

1 : 12000

0 1000 2000 3000 4000 5000 FEET

CONTOUR INTERVAL 80 FEET

BASE MAP: USGS NOGALES QUADRANGLE, 15 MINUTE SERIES

S.R. MOGER GEOLOGY MASTERS THESIS 1969

EXPLANATION

STRUCTURE

- Fracture
- Mineralized and/or altered fracture (width indicated, — pyrite, — sericite)
- Mineralized and altered zone (width indicated, — pyrite, — sericite)
- Fault

ALTERATION

- Epidote (approximate areas of strong alteration)
- Quartz (approximate areas of strong alteration)
- Sericite (dashed line indicates moderate alteration, solid line indicates strong alteration)
- Tourmaline

FIGURE 6

STRUCTURE AND ALTERATION MAP OF THE WEST CENTRAL PORTION OF THE PATAGONIA MOUNTAINS SANTA CRUZ COUNTY, ARIZONA

1:12000

0 1000 2000 3000 4000 5000 FEET

CONTOUR INTERVAL 400 FEET

BASE MAP: USGS NOGALES QUADRANGLE, 15 MINUTE SERIES

S.R. MOGER GEOLOGY MASTERS THESIS 1969