PETROLOGY OF PRECAMBRIAN GRANITIC ROCKS FROM THE LADRON MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

by

T. M. Cookro

Submitted in Partial Fulfillment
of the Requirement for the Degree of
Master of Science in Geology

New Mexico Institute of Mining and Technology

Socorro, New Mexico

June, 1978

CONTENTS

Page

TABLES

FIGURES

PLATES

Page

ABSTRACT

The Precambrian Capirote and Ladron quartz monzonite plutons form a large portion of the Ladron Mountains. A ternary Q-Ab-Or plot of both plutons shows a cluster of points near the minimum of Tuttle and Bowen (1958). The cluster of points for the Ladron pluton are much more closely packed than those of the Capirote pluton. The more scattered points representing samples of the Capirote pluton probably are due to secondary alteration and the large number of partially digested inclusions within the pluton. According to Tuttle and Bowen's (1958) classification both plutons can be termed subsolvus and both had a variable H_2O content.

The major minerals of the Capirote pluton are albitic plagioclase, quartz, perthitic microcline and highly altered biotite. The rocks of the Capirote pluton close to the contact with the Ladron quartz monzonite are highly albitized, probably due to the introduction of heat and the addition of Na from the Ladron intrusive. Essential minerals of the Ladron pluton are albitic plagioclase, quartz, perthitic microcline, muscovite and biotite.

ACKNOWLEDGMENTS

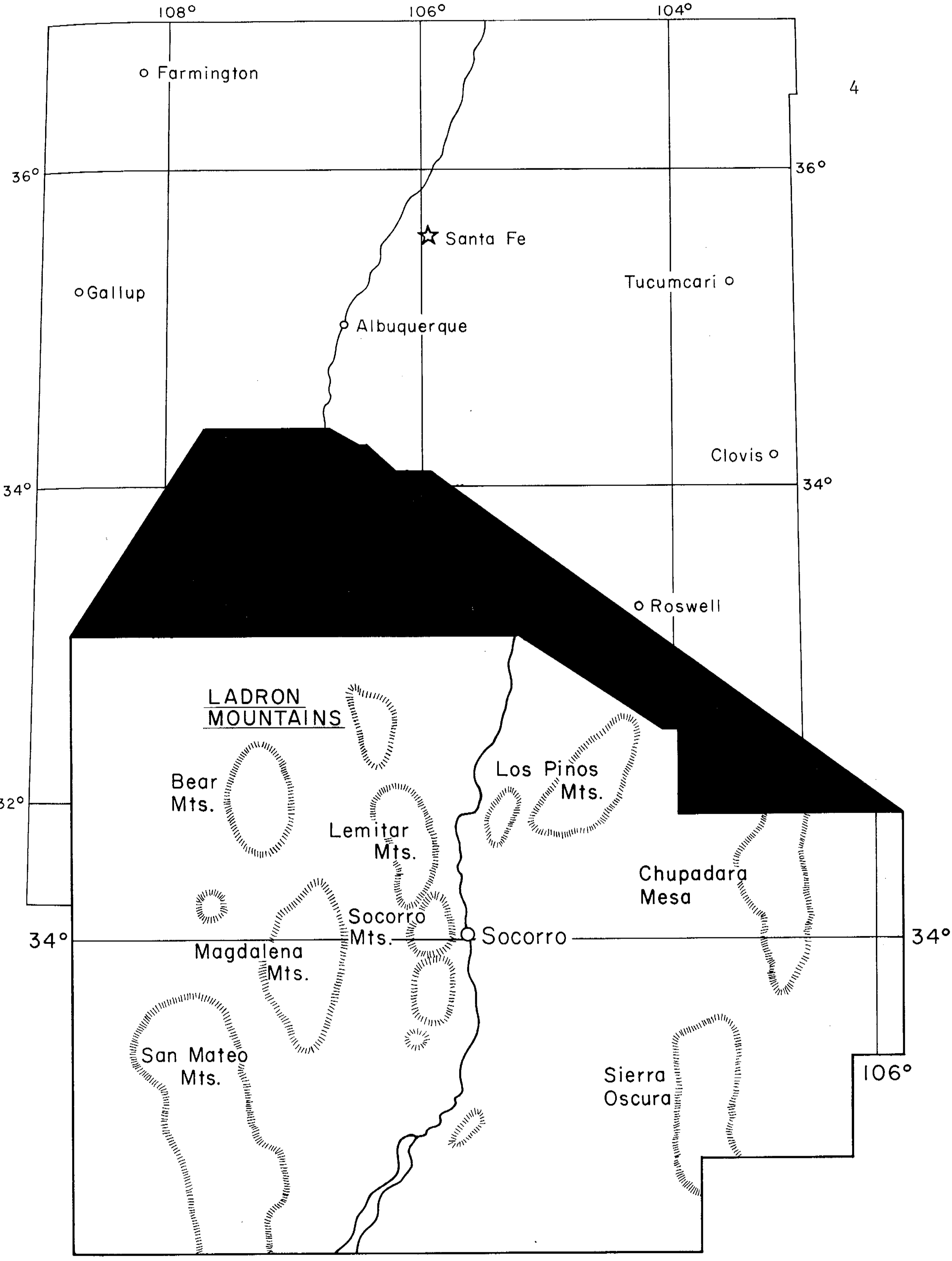
My thanks to Dr. Condie for his continued help and patience in guiding my investigation of the Ladron Mountains. Also, I sincerely appreciate the helpful suggestions of my committee members, Drs. Budding and Smith. And finally a special thanks to Larry Trom and Andrea Eddy for accompanying me on several field trips into the Ladrons.

INTRODUCTION

The purpose of this investigation is to describe in detail the field relations, petrography, and major-element geochemistry of the Precambrian granitic rocks exposed in the Ladron Mountains, New Mexico, in order to better understand the origin of these rocks.

The Ladron Mountains are approximately 50 km northwest of Socorro, New Mexico (figure 1), in the north-central portion of Socorro County. This north-trending fault-block range, located on the western edge of the Rio Grande rift system, is approximately 15 km long and 10.5 km wide with a total relief of about 1200 meters. The major stream draining the mountains is the Rio Salado, an eastward-flowing intermittent tributary of the Rio Grande. The mountains taper to the south, with the widest zone in the area of Ladron Peak; the most rugged portion faces eastward toward the Rio Salado and Rio Grande depression.

A large portion of the Ladron Mountains consists of Precambrian rocks (plate 1; figure 1). Condie, (1976) who mapped fifteen lithologic units, separates the Precambrian into three groups: 1)the quartzite sequence, consisting of five stratigraphic units, namely, amphibolite-phyllite, conglomeratic phyllite, quartzite, arkosite, and a feldspathic quartzite; 2)the metavolcanic sequence consisting of siliceous volcanics or hypabyssal rocks and amphibolites; and 3)an intrusive sequence consisting of the Capirote and Ladron quartz monzonite plutons. These two granitic plutons are the subject of this thesis.



(From Black 1964)

Figure 1. INDEX MAP SHOWING LADRON MOUNTAINS AREA.

Figure 1 Looking west at the Ladron Mountains

The mountains more barren of vegetation consists of Ladron quartz monzonite. Those more vegetated consist of the Capirote quartz monzonite.

Figure 2 Pennsylvanian units that unconformably overlie the Precambrian

The Capirote pluton is in the foreground.

The Madera and Sandia, Formations of Pennsylvanian age unconformably verlie the Precambrian rocks (plate 1; figure 2). These formations onsist of varying combinations of limestone, sandstone, and shale. he Permain San Andres Limestone (Black, 1964) is present on the astern side of the Ladrons. The fanglomerate facies (Bruning, 1973) f the Tertiary Popatosa Formation is located in the southeastern foot-ills. Here, the Popatosa is rich in Precambrian and late Paleozoic clasts. The Santa Fe Foramtion, a Tertiary Rio Grande valley fill deposit (Haederle, 1966), is found just east of the mountains. Quarternary pediment gravels are common on the southern Ladrons around Cerro Colorado. Noble (1950), Keely and Wood (1946), and Armstrong (1959) describe the cited formations in more detail.

Darton (1928) and Denny (1940) mapped the Ladron Mountains on a scale of 1:500,000 and 1:200,000, respectively. Noble (1950) mapped the southern end of the Ladrons, and Black (1964) mapped the northern and eastern sections for University of New Mexico Master's Theses. The structure and metamorphism of the Precambrian rocks were investigated by Haederle (1966) as Master's thesis at New Mexico Institue of Mining and Technology. Detailed mapping, petrography, major element and trace element geochemistry of the Precambrian rocks are in varying stages of completion by Condie (1976), Condie and Budding (1976, in preparation) an by the author.

METHOD OF INVESTIGATION

Sampling

The purpose of the field sampling was to collect representative rocks from the two Precambrian plutons of interest. Sampling, petrography, and chemical analysis reported herein suggest that only two major plutonic events are recorded in the Ladron Mountains. All sample locations are shown on the small geologic summary map from Condie (figure 2a). Three rock samples were taken from each location; one was used for preparation of a thin section, another for chemical analysis, and the third for inclusion in a reference set. The sampled outcrops are well exposed and reasonably accessible by a four wheel drive vehicle and by foot.

X-ray Fluorescence

The selection of rock specimens for chemical analysis was based on location of the sample, lack of secondary features such as epidote and quartz veins, and lack of weathering. Any weathered surfaces present on the samples were discarded during the gradual breakdown of the rock. Six samples of the Ladron quartz monzonite and twenty-one samples from various facies of the Capirote quartz monzonite were chosen for analysis using nondestructive X-ray fluorescence. Neutron activation was used to determine Na_2O content. Sample preparation and X-ray analysis were conducted using a procedure suggested by Dr. Condie.

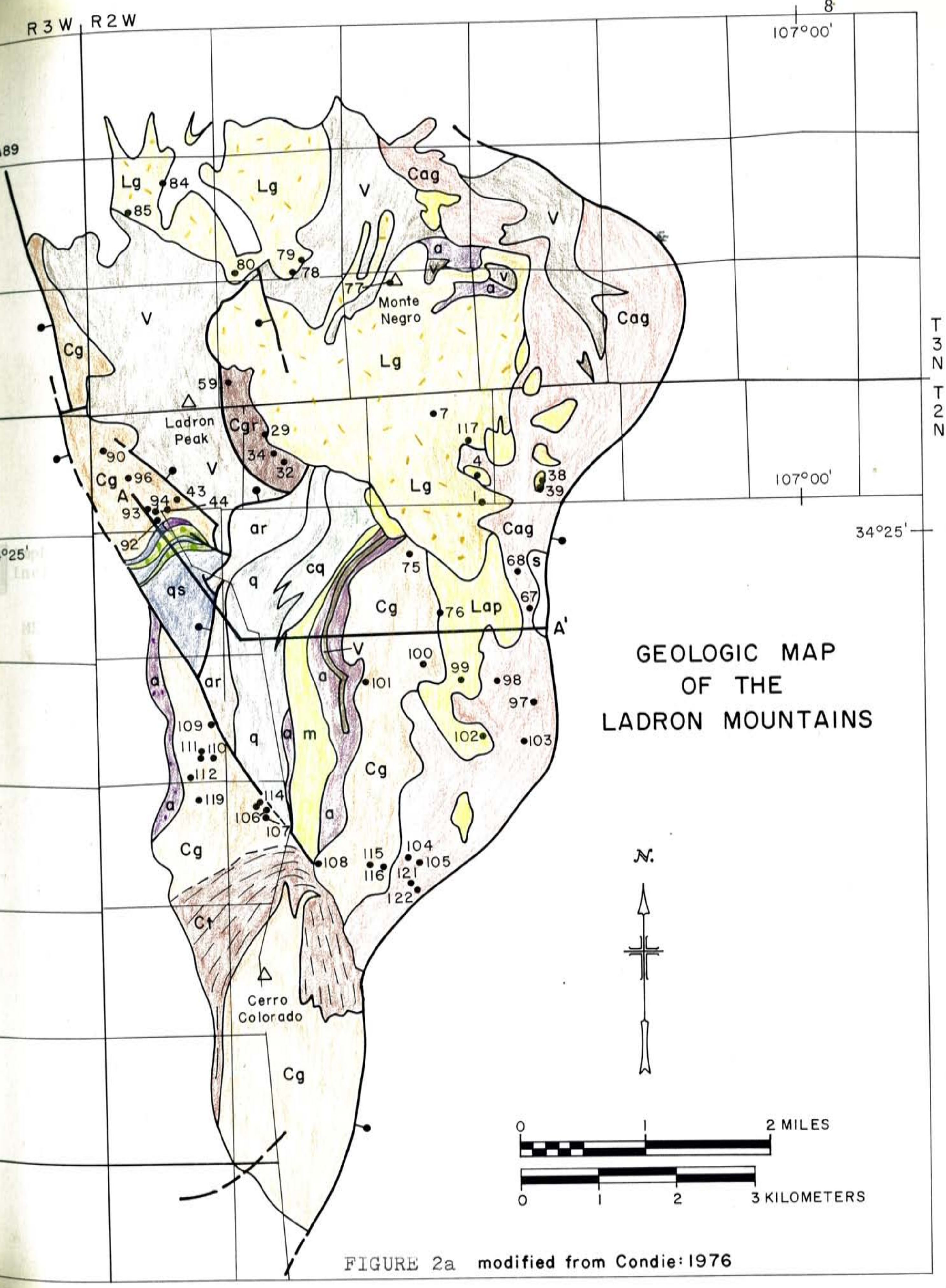


FIGURE 2a modified from Condie: 1976

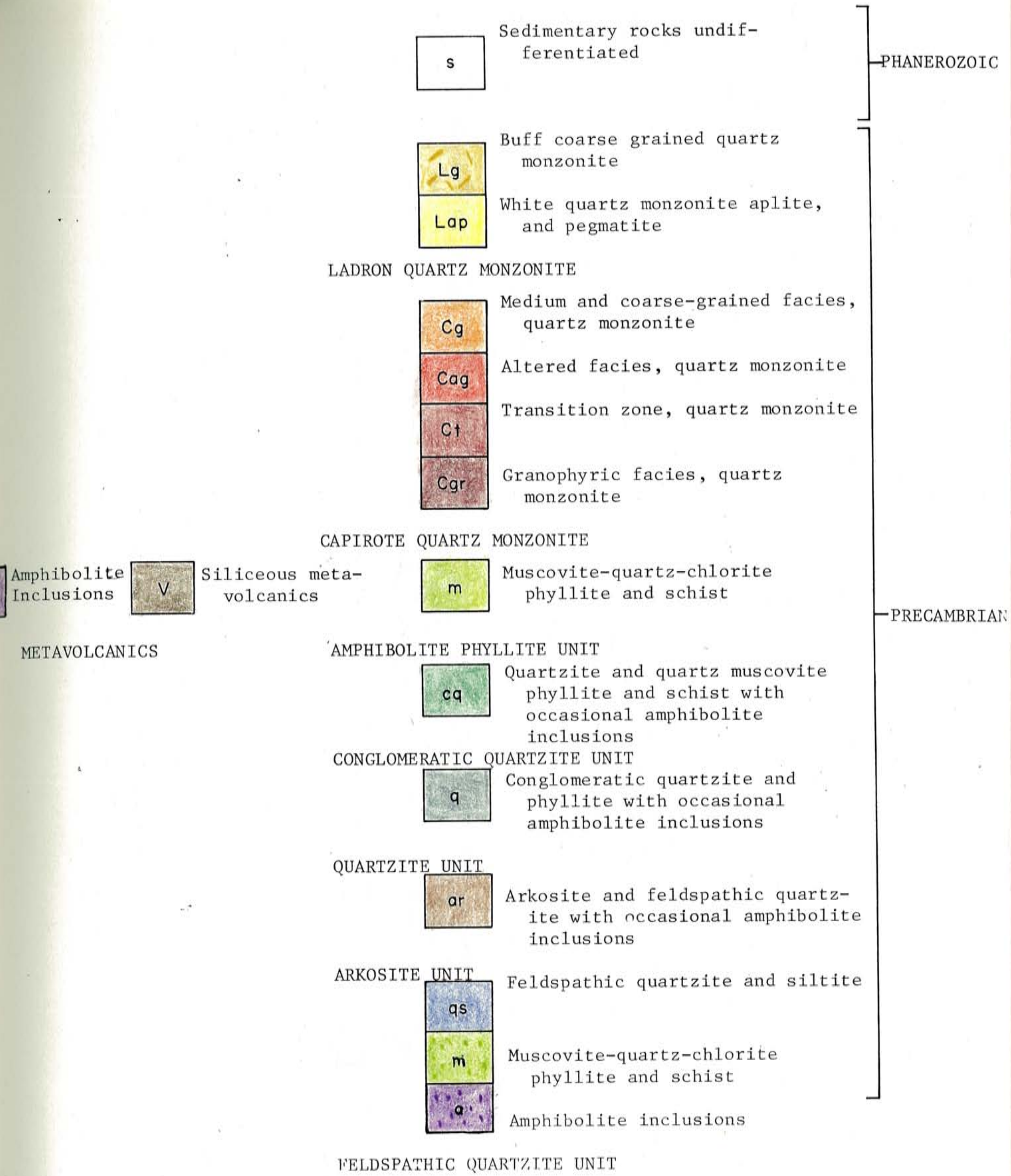
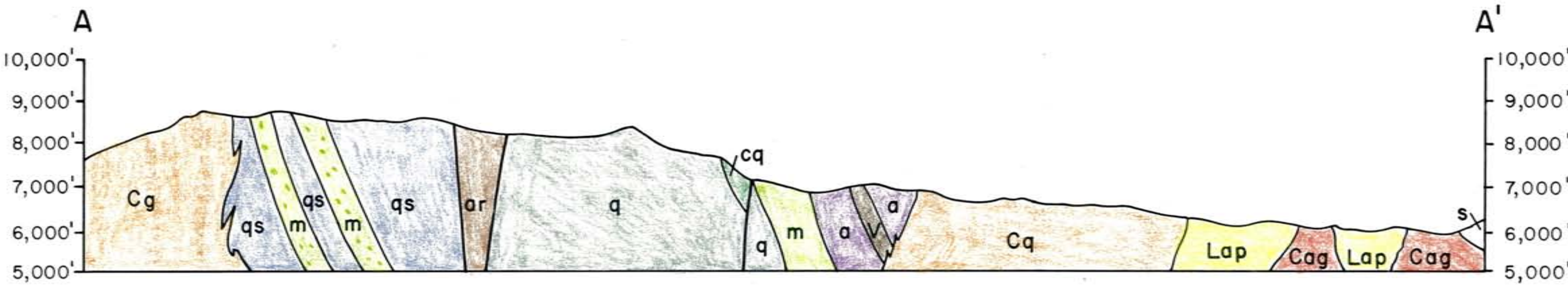

s
Sedimentary rocks undifferentiated
PHANEROZOIC
Lg
Buff coarse grained quartz monzonite
Lap
White quartz monzonite aplite, and pegmatite
LADRON QUARTZ MONZONITE
Cg
Medium and coarse-grained facies, quartz monzonite
Cag
Altered facies, quartz monzonite
Ct
Transition zone, quartz monzonite
Cgr
Granophyric facies, quartz monzonite
CAPIROTE QUARTZ MONZONITE
Amphibolite Inclusions
V
Siliceous metavolcanics
METAVOLCANICS
m
Muscovite-quartz-chlorite phyllite and schist
PRECAMBRIAN
AMPHIBOLITE PHYLLITE UNIT
cq
Quartzite and quartz muscovite phyllite and schist with occasional amphibolite inclusions
CONGLOMERATIC QUARTZITE UNIT
q
Conglomeratic quartzite and phyllite with occasional amphibolite inclusions
QUARTZITE UNIT
ar
Arkosite and feldspathic quartzite with occasional amphibolite inclusions
ARKOSITE UNIT
qs
Feldspathic quartzite and siltite
m
Muscovite-quartz-chlorite phyllite and schist
a
Amphibolite inclusions
FELDSPATHIC QUARTZITE UNIT

Figure 2b



CROSS SECTION A – A'

FIGURE 2c

Rock samples were crushed using a jaw crusher with steel plates, a chipmunk crusher (alumina plates) and an automatic pulverizer (alumina plates). Ten grams of the sample were ground for 20 minutes using a Fisher automatic grinder with an agate mortar and pestal; five grams of the ground sample were stored for later neutron irradiation; the remaider was ground an additional 30 minutes using acetone as a lubricant. Three grams of the finely ground sample combined with bakelite backing were placed in a steel die and sujected to a pressure of 20,000 psi for 10 minutes, a method suggested by Volborth (1963). Two drops of distilled water were added before pelletizing to prevent surface cracks from expanding when the pressure was released. Grinding equipment was cleaned thoroughly between samples with acetone.

Samples were analysed using a modified Philips 8-position vacuum spectopgraph equipped with W and Cr tubes and a simultaneous output printer. Rock Standards AGV-1, BCR-1, G-2, JB-1, JG-1, and SY-1, whose compositions are listed on Table 1, were used to construct major element calibration curves. A standard pellet was used to correct for electronic drift during XRF runs. Counts were accumulated in a fixed time mode. Each pellet was counted for 80-100 seconds (in 10 second intervals) for each element (Si, Al, Fe, Mg, Ca, K and Ti). Background corrections were necessary only for Mg. More detailed descriptions of the method are found in Volborth (1963), Norrish and Hutton (1969), Leake _et al._ (1968). Instrumental parameters for the element analysis are listed in Table 2.

Variables, such as pellet homogeneity, sample position, duration of counts, peak and background ratios, and operator error, must all be

TABLE 1. ROCK STANDARDS USED FOR X-RAY FLUORESCENCE ANALYSIS*

Standard	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2
G-2	69.11	15.40	2.65	0.76	1.94	4.07	4.51	0.50
AGV-1	58.99	17.25	6.76	1.53	4.90	4.26	2.89	1.04
BCR-1	54.50	13.61	13.40	3.46	6.92	3.27	1.70	2.20
SY-1	59.50	9.60	8.20	4.20	10.20	3.30	2.67	0.49
JG-1	72.24	14.21	2.21	0.73	2.18	3.39	3.96	0.26
JB-1	52.09	14.53	9.04	7.70	9.21	2.79	1.42	1.34

* most values recommended by Flanagan (1973)

TABLE 2. INSTUMENTAL PARAMETERS USED IN X-RAY FLUORESCENCE ANALYSES

Element	Peak	Target	Crystal	Detector	Gas	Collimator	Path	KV	MA
Si	K	Cr	EDDT	FPC[1]	P-10	Coarse	Vac[3]	45	25
Al	K	Mo	Gyp	FPC	P-10	Fine	Vac	45	35
Fe	K	W	LiF	Scin[2]	----	Coarse	Air	45	35
Mg	K	Cr	ADP	FPC	CH_4	Coarse	Vac	50	28
Ca	K	Cr	EDDT	FPC	P-10	Coarse	Vac	45	25
K	K	Cr	EDDT	FPC	P-10	Coarse	Vac	45	25
Ti	K	W	LiF	Scin	----	Coarse	Air	45	35
Rb	K	Mo	LiF	Scin	----	Coarse	Air	50	40
Sr	K	Mo	LiF	Scin	----	Coarse	Air	50	40
Zr	K	W	LiF	Scin	----	Coarse	Air	50	40

Counting Time: 10 seconds
1 FPC = flow proportional counter
2 Scin = scintillation counter
3 Vac = vacuum

considered in the total error. Condie (pers. comm.) has continually checked total error and found it to be expressed as one relative standard deviation of the mean, less than 5 percent for all elements except MgO, which is less than 10 percent. Pellet reproducibility is less than or equal to the overall error.

Neutron Activation

Samples (0.5 gram from the 5 grams set aside for N.A.) were sealed in polyethylene vials and sent to a nuclear reactor at Sandia Base in Albuquerque, New Mexico for irradiation. Samples were subjected to a thermal neutron flux of 5×10^{11} n/cm^2/sec for 5 minutes for Na_2O analysis. Dr. Condie has conducted tests to evaluate lateral and vertical flux inhomogeneities and found them negligible. Sample cooling period was 10-24 hours; counting peak, 1368 keV (γ), and counting time, 6.0×10^2 seconds. A Ge (Li) drifted detector system, Canberra 4096 channel gamma ray spectrometer is used in counting radioisotopes. The U.S.G.S. standard G-2 and an intralab granitic rock standard LOSP were irradiated with the samples. Table 3 summarizes pertinent data for the standards. Values listed for G-2, are recommended by Flanagan (1973). The method used in neutron activation is further described in Condie and Lo (1971), and Schroeder and Winchester (1962). Analytical error is continually checked by Condie and is found to be about 3 percent for Na_2O.

TABLE 3. NEUTRON ACTIVATION GRANITE STANDARDS

	G-2	LOSP
SiO_2	69.11	76.00
Al_2O_3	15.40	12.40
Fe_2O_3 (total Fe)	2.65	1.87
MgO	0.76	0.07
CaO	1.94	0.60
Na_2O	4.07	3.45
K_2O	4.51	4.80
TiO_2	0.50	0.22

Norms

A program for the determination of both meso- and CIPW norms was used for calculations. The input consisted of data for the oxides SiO_2, Al_2O_3, FeO (total Fe), MgO, Na_2O, K_2O and CaO. The oxide data was converted to moles by dividing each oxide value by the individual molecular weights. The program then proceeded to fit the moles to a mineralogical sequence defined in Cross et al. (1902) and Barth (1959).

Fe^{+2} and Fe^{+3} were not distinguished in the analytical process; therefore the amount of iron needed for modal iron oxides and sulfides was subtracted from total Fe and the remainder, expressed as FeO, was put into normative biotite with MgO.

Volatile elements H_2O and CO_2 were not determined in the samples. Based on similar granitic rocks for which the amounts of those elements and P_2O_5, MnO, and SO_2 are known, the major element totals were recalculated to 99.5 percent leaving 0.5 percent for minor elements not determined.

Modal Analysis

Modal analyses of 57 thin sections with means and standard deviations are listed in Tables 4-8 for the Capirote pluton and Table 9 for the Ladron pluton. Chayes (1956), and Van der Plas and Tobi (1965) describe the point-counting techniques used in this investigation. In the counting an attempt was made to pass over the entire surface of the thin section. The point distance chosen was larger than the largest grain fraction included in the analysis. With about 1500 counts per thin section, a 95-percent confidence is achieved and a 2-percent counting error is expected (Van der Plas and Tobi (1965).

TABLE 4. CAPIROTE QUARTZ MONZONITE MODAL ANALYSES (VOLUME PERCENT)

Mineral	Rock Samples										
	LD86	LD88	LD89	LD90	*LD92	*LD93	*LD94	*LD96	LD100	LD101	LD106
Quartz	30.0	48.0	36.0	46.0	45.0	35.0	24.0	38.0	38.0	35.0	27.0
Microcline	34.0	30.0	39.0	31.0	26.0	15.0	27.0	51.0	49.0	9.2	14.0
Plagioclase	35.0	21.0	25.0	20.0	26.0	33.0	45.0	9.0	10.0	55.0	53.0
Biotite	0.0	0.0	0.0	0.2	2.0	13.0	0.1	0.7	0.1	0.0	1.5
Sericite	0.0	0.0	2.0	0.4	0.3	0.1	2.0	0.2	0.0	0.0	0.1
Epidote	0.2	0.0	0.0	0.0	0.2	2.4	1.0	0.1	0.3	0.3	2.8
Fluorite	0.0	0.1	0.0	0.1	0.0	0.2	0.0	0.6	0.0	0.0	0.0
Opaques	0.3	0.1	0.0	0.4	0.7	0.4	0.6	0.4	0.0	0.4	0.0
Non Opaque Accessories+	0.1	0.1	0.0	0.1	0.1	1.1	0.4	0.1	0.1	0.0	1.8
Plagioclase An Content Using XRD								13.0			

* = Coarse Grained Facies
\+ = Allanite, Apatite, Chlorite, Sphene, Zircon

TABLE 5. CAPIROTE QUARTZ MONZONITE MODAL ANALYSES (VOLUME PERCENT) Continued

Minerals	Rock Samples													
	LD107	LD108	LD110	LD111	LD112	LD113	LD114	LD115	LD116	LD118	LD119	$\bar{X}$	$\bar{X}$ Coarse	STD	STD Coarse
Quartz	24.0	35.0	42.0	34.0	30.0	31.0	30.0	35.0	37.0	42.0	24.0	35.0	35.0	7.0	8.0
Microcline	22.0	31.0	26.0	36.0	42.0	40.0	18.0	48.0	31.0	31.0	4.0	30.0	30.0	12.0	13.0
Plagioclase	51.0	28.0	28.0	29.0	25.0	27.0	47.0	12.0	28.0	23.0	55.0	32.0	28.0	14.0	13.0
Biotite	0.1	3.0	0.1	0.4	0.0	1.0	1.0	2.5	2.0	0.5	1.8	0.8	4.0	1.0	5.3
Sericite	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.6	0.5	0.8
Epidote	3.0	3.0	0.0	0.2	0.6	1.0	0.2	2.0	1.0	0.0	9.6	1.3	0.9	2.3	0.9
Fluorite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.05	0.2
Opaques	0.0	0.3	2.4	0.0	0.5	0.5	0.7	0.3	1.0	0.9	1.3	0.5	0.5	0.6	0.1
Non Opaque Accessories+	0.4	0.2	0.1	0.6	2.0	0.0	2.4	0.3	0.2	2.0	4.0	0.8	0.4	1.1	0.4
Plagioclase An Content Using XRD			13.0						12.0						

+ = Allanite, Apatitie, Chlorite, Sphene, Zircon
$\bar{X}$ = Mean
STD = Standard Deviation

TABLE 6. CAPIROTE QUARTZ MONZONITE MODAL ANALYSES

(VOLUME PERCENT) ALTERED FACIES

Mineral	Rock Samples													
	LD4	LD67	LD68	LD75	LD76	LD97	LD89	LD99	LD103	LD104	LD105	LD117	$\overline{X}$	STD
Quartz	39.0	35.0	32.0	42.0	36.0	26.0	30.0	24.0	29.0	30.0	3.4	36.0	30.0	9.5
Microcline	32.0	27.0	0.0	44.0	40.0	5.0	23.0	0.0	1.0	26.0	19.0	32.0	21.0	15.0
Plagioclase	27.0	35.0	58.0	12.0	20.0	69.0	43.0	76.0	60.0	39.0	71.0	31.0	45.0	20.0
Biotite	1.0	0.2	0.0	0.1	0.5	0.0	0.0	0.0	0.8	3.0	0.0	0.5	0.5	0.8
Sericite	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.4
Epidote	0.1	0.0	5.3	0.0	3.0	0.0	3.7	0.0	6.7	2.0	5.4	0.2	2.2	2.4
Fluorite	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
Opaques	0.1	0.4	2.7	0.6	0.0	0.1	0.1	0.0	0.0	0.3	0.6	0.3	0.4	0.7
Non Opaque Accessories+	0.0	2.0	1.4	0.1	0.4	0.0	0.1	0.3	0.4	0.0	0.0	0.4	0.4	0.6
Plagioclase An Content Using XRD							14.0		5.0					

+ = Apatite, Chlorite, Sphene, Zircon

$\overline{X}$ = Mean

STD = Standard Deviation (see Table 5)

TABLE 7. CAPIROTE QUARTZ MONZONITE MODAL ANALYSES

(VOLUME PERCENT) GRANOPHYRIC FACIES

Mineral	Rock Samples				
	LD32	LD34	LD59	$\overline{X}$	STD
Quartz	53.0	53.0	45.0	50.0	4.0
Microcline	28.0	22.0	41.0	30.0	8.0
Plagioclase	12.0	18.0	9.4	13.0	4.0
Biotite	1.4	2.0	0.0	1.1	0.8
Muscovite	4.8	3.0	3.0	3.6	0.8
Epidote	0.0	0.0	0.1	0.0	0.5
Fluorite	0.0	0.0	0.0	0.0	0.0
Opaques	0.8	0.9	1.0	0.9	0.1
Non Opaque Accessories +	0.2	0.7	0.5	0.5	0.2
Plagioclase An Content Using XRD	20.0				

+ = Chlorite and Sphene
$\overline{X}$ = Mean
STD = Standard Deviation (see Table 5)

TABLE 8. MODAL ANALYSES OF THE CAPIROTE PLUTON NEAR++ THE CONTACT WITH THE WHITE FACIES OF THE LADRON PLUTON**

Minerals	Rock Samples									
	LD121-1	LD121-2	LD121-3*	LD122A	LD122B	LD122C	LD122D	LD122E*	$\overline{X}$	STD
Quartz	37.0	30.0	39.0	45.0	38.0	36.0	30.0	28.0	35.0	5.0
Microcline	26.0	29.0	28.0	24.0	28.0	39.0	30.0	41.0	32.0	6.0
Plagioclase	28.0	23.0	24.0	25.0	28.0	16.0	38.0	28.0	26.0	6.0
Biotite	0.4	0.6	0.1	0.3	0.0	0.2	0.2	0.0	0.0	0.2
Muscovite	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epidote	8.0	6.2	8.0	1.1	0.0	7.6	0.1	0.1	4.0	3.6
Fluorite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Opaques	0.2	0.1	0.1	0.3	0.9	0.3	1.0	1.0	0.5	0.4
Non Opaque Accessories+	0.7	5.3	1.0	4.4	5.1	1.0	1.0	1.0	2.4	1.9

* = Adjacent to Ladron Pluton
** = In volume percent
+ = Chlorite, Sphene, Zircon
++ = Distance between samples approximately 1 meter
$\overline{X}$ = Mean
STD = Standard Deviation (see Table 5)

TABLE 9. LADRON QUARTZ MONZONITE MODAL ANALYSES (VOLUME PERCENT)

Mineral	Rock Samples												
	*LD1	LD7	LD38	LD39	LD44	LD77	LD78	LD79	LD80	LD84	LD85	*LD102	$\overline{X}$	STD
Quartz	36.0	32.0	29.0	38.0	41.0	32.0	30.0	29.0	17.0	34.0	28.0	31.0	31.0	5.7
Microcline	32.0	24.0	30.0	18.0	34.0	27.0	30.0	27.0	29.0	29.0	35.0	29.0	29.0	4.3
Plagioclase	31.0	35.0	35.0	38.0	25.0	32.0	33.0	36.0	40.0	30.0	26.0	34.0	33.0	4.3
Biotite	0.0	3.0	0.0	0.0	0.1	0.0	2.8	4.6	0.0	2.8	5.0	0.1	1.5	1.9
Muscovite	0.1	4.0	6.0	4.0	0.3	6.0	3.4	2.8	6.0	1.7	4.7	4.7	3.6	1.2
Epidote	0.0	0.7	0.0	0.0	0.0	3.0	0.9	0.0	5.0	2.0	0.2	0.8	1.1	1.5
Fluorite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.2	0.6
Opaques	0.7	0.1	0.1	0.8	0.5	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.2	0.3
Non Opaque Accessories+	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.0	0.5	0.0	2.0	0.1	0.3	0.6
Plagioclase An Content Using XRD								13		13		13		

* = white facies
\+ = Apatite, Chlorite, Zircon
$\overline{X}$ = Mean
STD = Standard Deviation = (see Table 5)

Minerals such as apatite, zircon, chlorite, sphene and allanite, were all considered nonopaque accessories; large grains of albite within perthitic microcline were considered plagioclase; and large grains of sericite were listed under muscovite. Other mineral titles are definitive. All thin sections were stained for potassium feldspar using sodium cobaltinitrite, employing the method of Bailey and Stevens (1960).

Anorthite Content of the Plagioclase

The semi-quantitative method of Smith and Yoder (1956) was used to determine the An content of the plagioclase. Methods using plagioclase twinning were impossible because most of the plagioclase grains in both plutons are untwinned or exhibit poorly developed twinning. Powders of hand-picked plagioclase from rock samples were firmly packed into a well in an aluminum plate that was slightly larger than the field of X-ray penetration. A Norelco high angle diffractometer, using copper K α radiation was put on a scan speed of 1/4° per minute and a chart scale of two inches per degree. The appropriate 2θ was scanned and reflection separations of $(1\bar{3}1)$ and (131) were measured to the nearest 0.10° 2θ. The $(1\bar{3}1)$ and (131) reflections were used because: 1) they are clearly resolved from neighboring reflections; 2) their 2θ values are sensitive to composition; and 3) the two reflections are close together in powder patterns, thus helping to minimize chart scale errors (Smith and Yoder, 1956). The method is semi-quantitative because other reflections measured by Smith and Yoder did not produce the same values, and the state of inversion of plagioclase is not certain because of lack of knowledge concerning the relative importance of the factors influencing it (Smith and Yoder, 1956). Six samples were chosen for X-ray analysis from the Capirote pluton and three from the Ladron pluton. One sample was taken from the granophyric facies of the Capirote, two from the altered facies (one of which was from a highly albitized sample), and three from the unaltered facies. Values obtained using this method are listed on Table 4-9.

CAPIROTE QUARTZ MONZONITE

General Character

The Capirote quartz monzonite of the Ladron Mountains crops out in a roughly circular pattern (figure 2a). The pluton crops out extensively in the southern part of the mountains, around Cerro Colorado. Exposure is very good and totals about 30 km^2. The intrusive forms low rounded hills.

The Capirote quartz monzonite varies considerably in composition and texture. Four facies are evident in the field:

1. A medium-grained facies (3-5 mm grain size)
2. A coarse-grained facies (5-10 mm grain size)
3. An altered facies (1-5 mm grain size)
4. A granophyric facies (1-3 mm grain size)

The medium- and coarse-grained facies are mineralogically similar. The medium-grained facies is found as four discontinuous outcrops in the western and central parts of the mountains (Condie, 1976). The coarse-grained facies is found only in one small area, southwest of Ladron Peak (figure 2a). The contact of the two facies is gradational and both are described as one throughout the text. Outcrops are light to rusty brown, due to iron oxide staining. The essential minerals are albitic plagioclase, quartz, and perthitic microcline. Epidote veins approximately 3-10 mm in thickness fill rock fractures and are quite common. These two facies have equigranular textures and for the most part lack foliation, although faulting and partially digested inclusions have caused some minor foliation in a few areas. The coarse-grained facies is distinguished from the medium-grained facies by a slight increase in chlorite content and in grain size.

The altered facies is exposed along the eastern edge of the mountains and is gradational with the medium-grained facies. It is highly fractured and faulted, and often deeply altered (probably by hydrothermal fluids). Outcrops are light rusty brown and white, due to iron-oxide staining and the white color of the microcline. The texture ranges from massive to gneissic. A general alignment of biotite and quartz aggregates defines the foliation. The fractures and faults in the altered facies seem related to Cenozoic movement of the Jeter and Cerro Colorado faults (Condie, 1976). A portion of the altered facies consists of up to 80 percent partially granitized phyllites, quartzites, and siliceous (?) metavolcanics. This zone wraps around the northern part of Cerro Colorado and is shown on the map (figure 2a). Essential minerals of the altered facies are plagioclase, coarsely perthitic microcline, and quartz.

The granophyric unit is located southeast of Ladron peak (figure 2a). It is named for the granophyric intergrowth which is prominent as interstitial mineral growth. The term "granophyric intergrowth" is used in the same context as Barker's (1970) paper: "Granophyric intergrowths involve quartz and alkali feldspar, intergrown on scales from submicroscopic to 1 or 2 mm. Approximately equal amounts of quartz, $NaAlSi_3O_8$ and $KAlSi_3O_8$ participate in most of these intergrowths,. . ." The weathered surface of the granophyric facies is light brown to rusty orange. A fresh surface often exhibits equigranular texture and is brown and white, due to interstitial iron oxide and feldspars. In some hand specimens, rocks of the granophric facies show an alignment of quartz and mafic minerals due to Cenozoic faulting in the area. Minerals in these samples show evidences of mechanical deformation. Essential minerals are quartz, microcline, and plagioclase with an intergrown matrix of the same three minerals. Geochemically and petrographically it is generally similar to the other facies mentioned. An outcrop of medium to coarse-grained Capirote quartz monzonite, west of the granophyric facies (LD 90 series on figure 2a) contains minor interstitial granophyric intergrowths (figure 1; Plate 2).

Contact Relationships

In general, contact relationships are poorly exposed. The white facies of the Ladron quartz monzonite interfingers with the Capirote pluton. Lobes of the white facies are found commonly around the Brown (Lazy C Bar J) Ranch (plate 5, figure 2). The contact with the main body of the Ladron pluton forms a sinuous pattern. Actual contacts with the Ladron quartz monzonite are sharp (1-3 m wide). To better describe the detailed nature of the contact, successive samples of Capirote quartz monzonite were taken in two locations near the contact of the white facies of the Ladron pluton (Table 8). At the contact, the Capirote quartz monzonite is a lighter color, more dense, and the rock is altered. Chlorite, sphene, and specular hematite are relatively abundant. Calcite has been introduced along some parts of the contact zone through marginal fissures. Modal evidence does not show higher quartz content but the Capirote pluton appears to be more dense near the contact with the Ladron pluton.

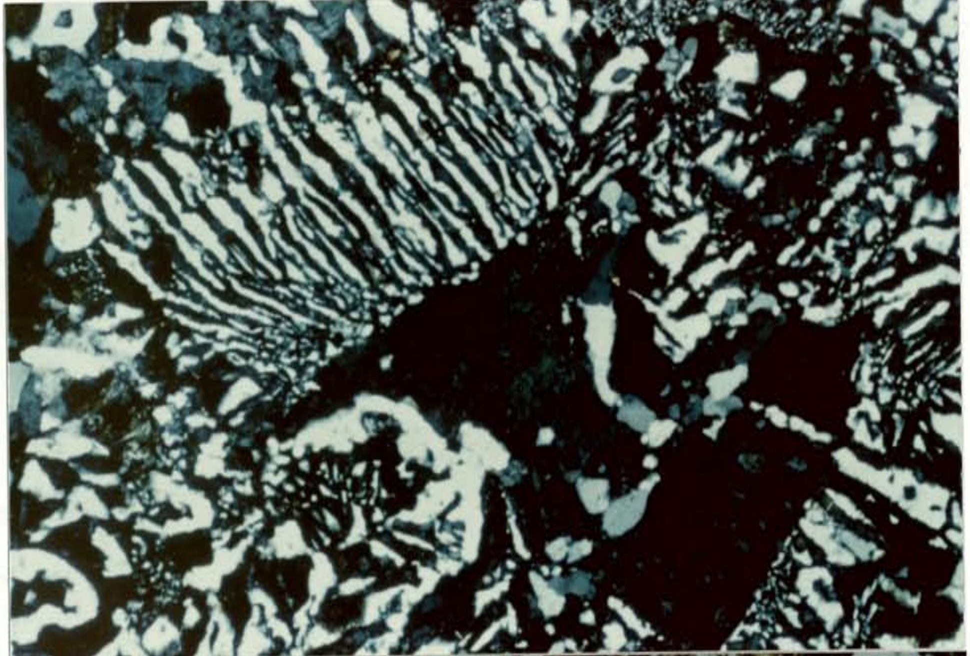


Figure 1
Capirote pluton, LD 96
coarse facies
granophyre
crossed polarizers
40x

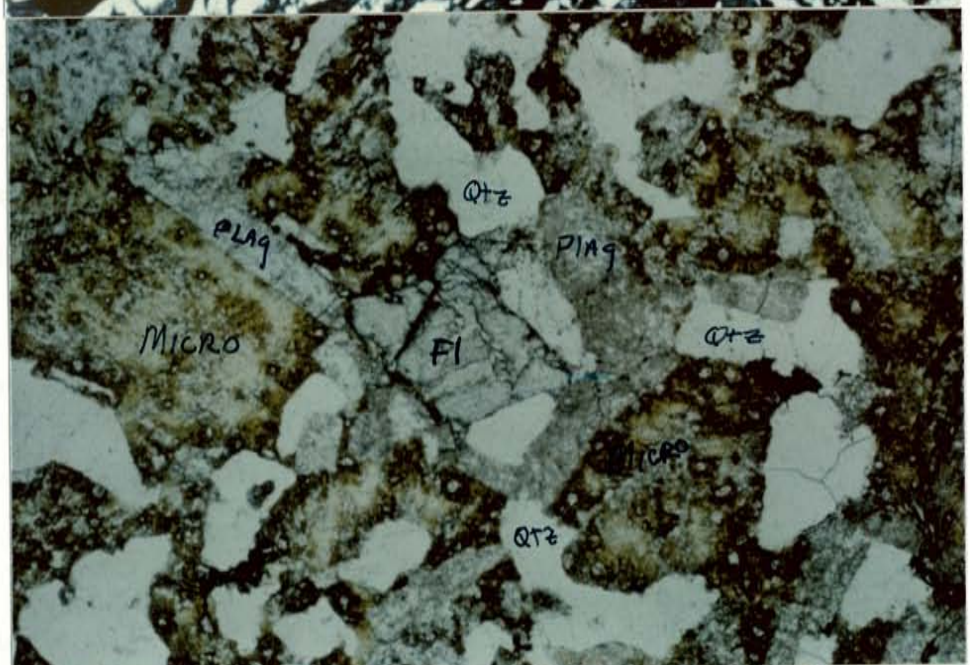


Figure 2
Capirote pluton, LD 96
coarse facies
primary fluorite
uncrossed polarizers
40x

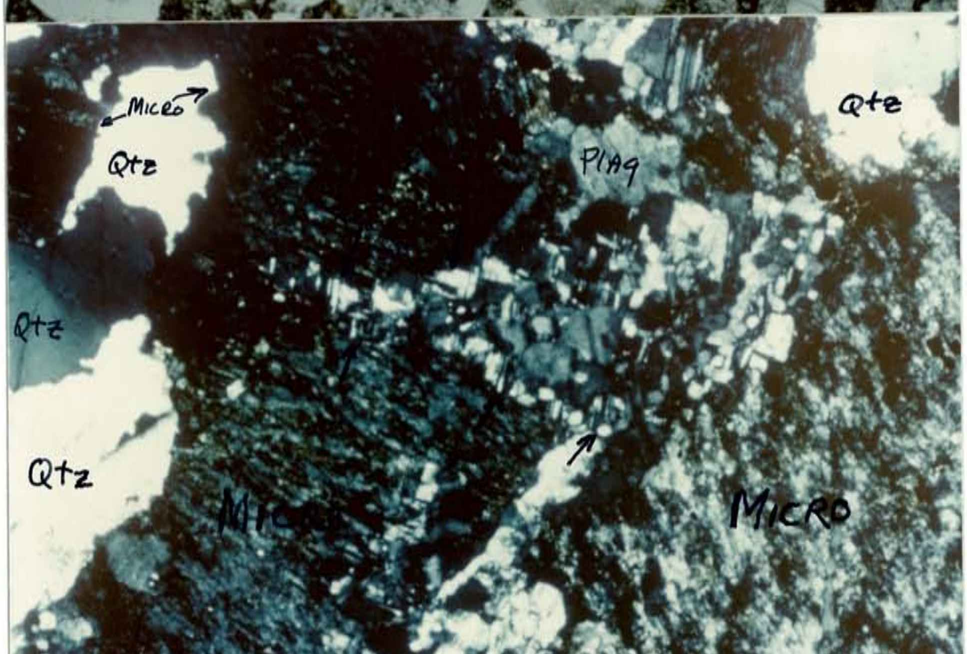


Figure 3
Capirote pluton, LD 75
altered facies
twinned plagioclase
vein fillings
crossed polarizers
40x

The ridge southeast of Monte Negro is a good location for observing contact relationships of the Capirote pluton with the older metavolcanic rocks. The metavolcanics have been replaced and intruded by granitic material from the Capirote quartz monzonite. The shape of the contact in map view is jagged and blocky. Large inclusions of the volcanics can often be found near the contact zone. The contact itself is relatively sharp, approximately 3-5 meters in width. The magma seems to have worked its way into the volcanic rocks through small marginal fractures, perhaps related to the intrusion, and through replacement processes. In some areas near the contact, epidote and quartz have permeated the rock, resulting in a pistachio green color and finer grain size.

The contact with the older quartzite unit is similar to the volcanic contact. A gradual change in K-feldspar content in going from the contact into the quartzite is evident. The quartzite near the contact has a pink color and contains stringers of granitic material, porphyroblasts of feldspar, and a marginal replacement by granitic material. Going in the direction of the main body of quartzite, the quartzite sequence becomes light gray in color. The contact zone ranges from 4 to 8 meters, and in map view the contact is rather sinuous and lobate in form.

Dikes

Three types of dikes cut the Capirote pluton: quartz (?) monzonite, amphibolite, and metadiabase dikes. The quartz (?) monzonite dikes are northeasterly trending and approximately 1-3 m in thickness. These dikes have a minor amount of copper mineralization within them. One of the dikes crosses the road going into the Brown Ranch. It can be found approximately 1.6 km east of the Brown (Lazy C Bar J) Ranch. A prospect pit is on the south side of the road at this location on the western margin of the dike. These dikes do not appear related to the Capirote or Ladron quartz monzonites. Some of them cross-cut younger sediments to the east.

The older amphibolite dikes strike N to N25W and their average thickness is from 1 to 2 m. These amphibolites are permeated by quartz and aplite stringers, and marginally are penetrated by pink potassium feldspar. The dikes are numerous and well indurated, weathering out as massive rounded cobbles or boulders.

The younger metadiabase dikes have a northeast trend, average from 0.5 to 1 m in thickness, and have a very sharp contact with the Capirote pluton. The weathering habit of these dikes is often platy. The plates are parallel to the margins of the dikes and the rock is more brittle than the amphibolite.

Inclusions

The Capirote quartz monzonite contains a large number of inclusions. The number of inclusions increases to about 50 percent or more around the northern edge of Cerro Colorado. Quartzite, amphibolite, schist and siliceous metavolcanic rock are the most common types of inclusions found. Some of these are oriented in that they wrap around Cerro Colorado in a circular pattern (see Condie, 1976). They may be roof pendants. The inclusions are irregular in shape, appear blocky and sometimes more rounded. These inclusions are often found in groups. The size range varies tremendously from large (1-2 km long) blocks to fragments of about 10 cm in size. Winding stringers of K-feldspar and sometimes milky quartz invade the inclusions from their margins. The contact with the host rock is somewhat gradational, ranging from 5 cm to 1 m in width. Many inclusions give the appearance of being partially granitized by K-feldspar and quartz. K-feldspar porphyroblasts are common in the inclusions of quartzites and metavolcanics. Exposed Precambrian metavolcanics, quartzites, and schists found in the Ladron Mountains appear to be the source of the inclusions.

Aplites, Pegmatites and Quartz Veins

Aplite and pegmatite stringers are rare, only 3-5 cm in width, and several meters in length. They are found generally in contact areas of inclusions or extending into the older Precambrian rocks. Aplite dikes originating from the Ladron pluton are more common. Milky quartz veins (description in following chapter) are found radiating from the Ladon quartz monzonite into the Capirote pluton filling zones of weakness.

Petrography

Hand Samples

In hand specimen, the medium-grained facies of the Capirote quartz monzonite is light pink and gray due to the iron oxides in the microcline and cloudy quartz grains. The weathered surface is a rusty brown. The coarse-grained facies is mottled, light pink and black due to the greater amount of mafic material. The granophyric facies is light pink and white, fine-grained and considerably different in appearance than the other facies. It has the appearance of being a volcanic rock until seen in thin section. Some granophyric specimens exhibit an alignment of mineral constituents due to later mechanical deformation. (This problem is discussed in detail in the section on "Granophyric Intergrowth," pp. 41-46.) In all specimens, the fabric is holocrystalline, phaneritic, and consists of subhedral to anhedral grains. Mafic constitutents are generally minor.

Modal Analysis

Statistical thin section analysis of 21 unaltered Capirote quartz monzonite samples, 14 samples from the altered facies and 3 from the granophyric facies, using point counting techniques are listed in Tables 4-8. Sampling locations are given on figure 2a. The composition of these rocks defines a trend towards albitization in the transition from the unaltered to altered facies of the Capirote pluton as discussed later.

A plot on the quartz-plagioclase-K feldspar classification triangle (figures 3 & 4) shows that both the altered and unaltered facies fall in the quartz monzonite field. The modal composition shows the diversity of this pluton. This diversity appears to reflect some combination of the large number of inclusions within the Capirote intrusive, the movement of fluids that caused replacement textures, and the enrichment of albite. There is a distinct compositional trend in the Capirote pluton going from the quartz monzonite to granodiorite to quartz diorite compositional fields. The mechanism for this albitization process is difficult to define.

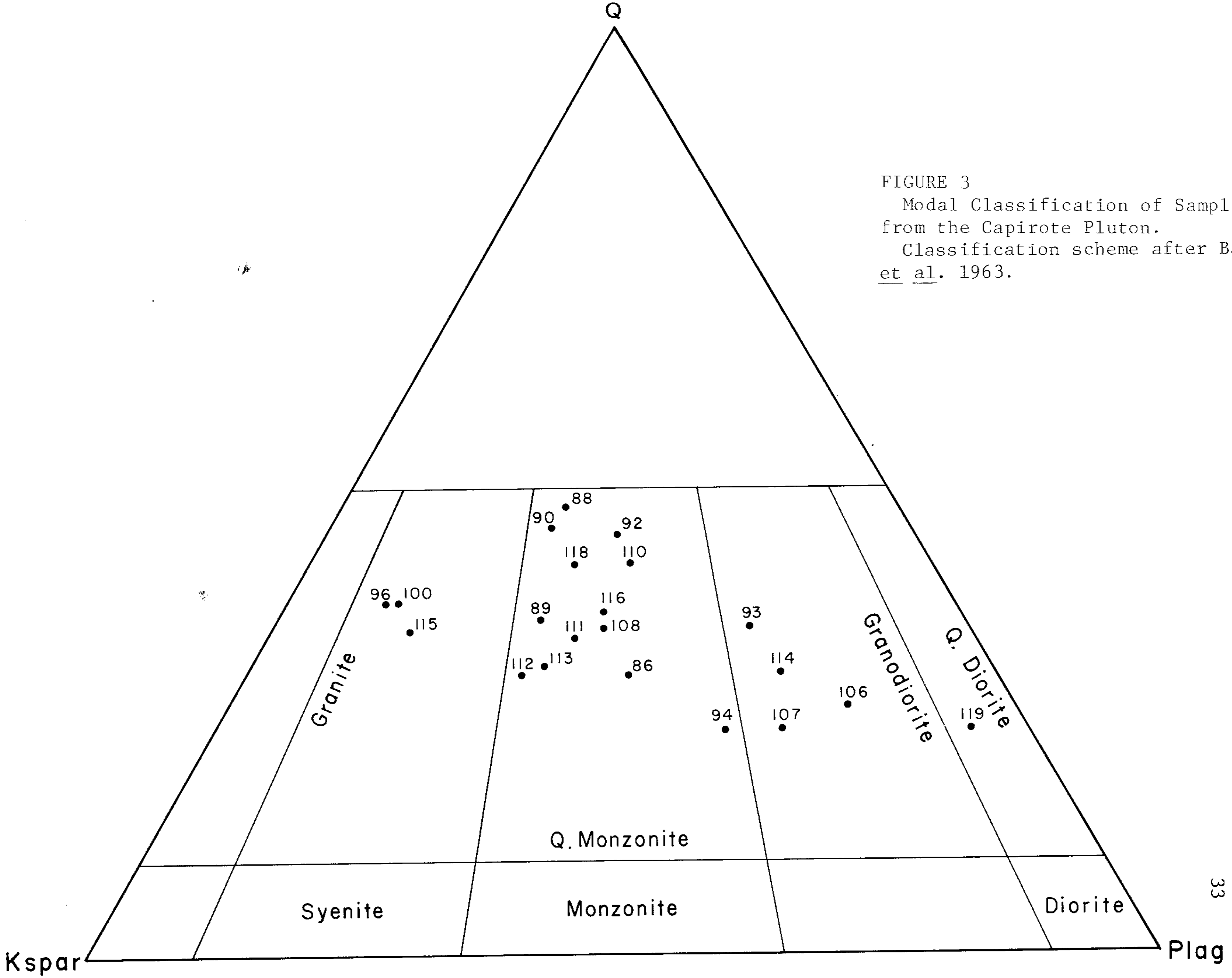


FIGURE 3
Modal Classification of Samples from the Capirote Pluton.
Classification scheme after Bateman _et al_. 1963.

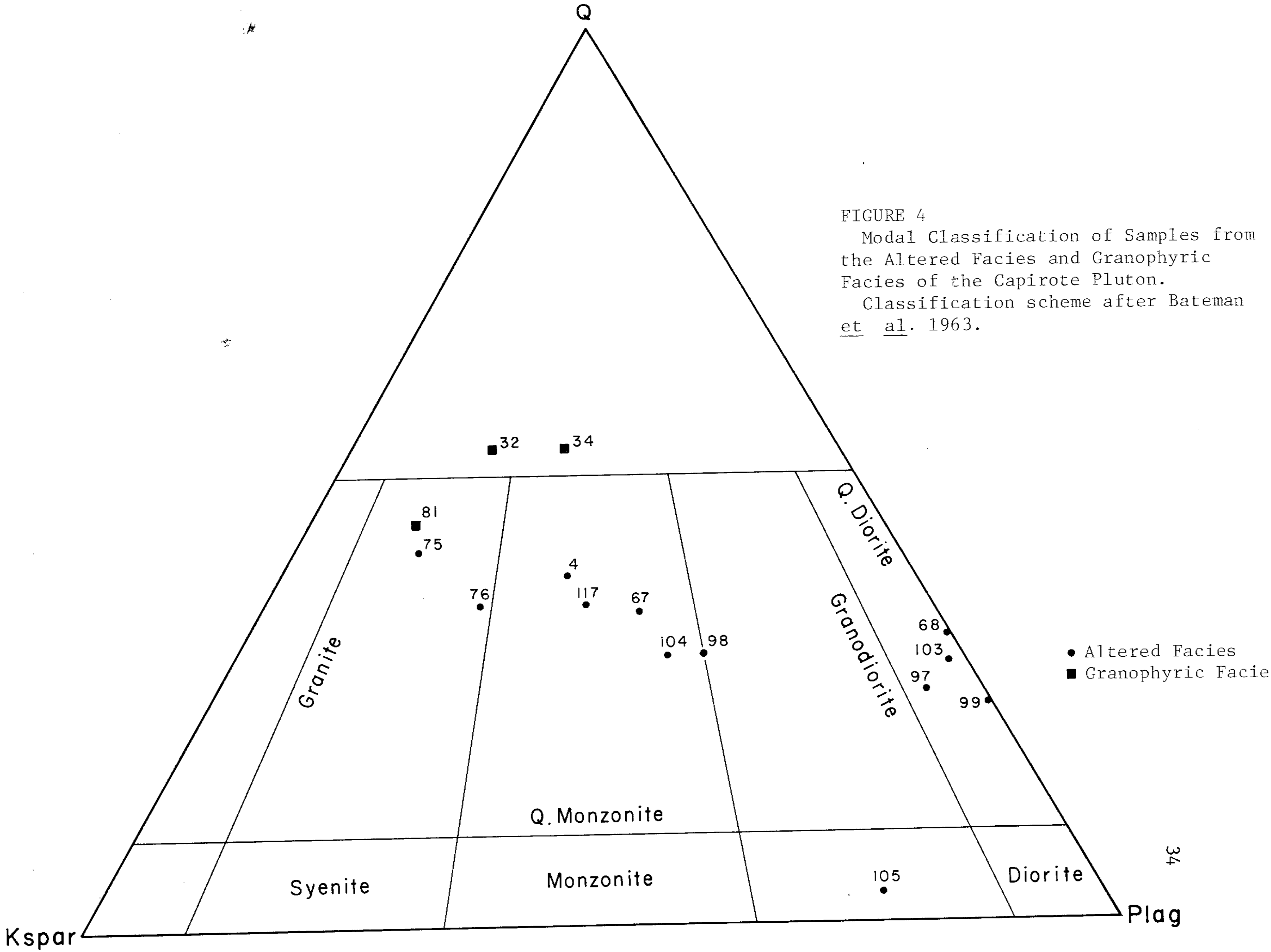


FIGURE 4
Modal Classification of Samples from the Altered Facies and Granophyric Facies of the Capirote Pluton.
Classification scheme after Bateman _et al_. 1963.

Mineral Descriptions

Plagioclase

There are four distinctive types of plagioclase in the Capirote pluton. The first consists of subhedral to anhedral grains generally 1-3 mm in length. These crystals, because they are generally large, subhedral, and have other minerals growing interstitially around them, are considered to have formed early in the crystallization sequence. Another variety of plagioclase is less than 1 mm in diameter, exhibits albite twinning, and is often found as veinlets or in intersitial positions (plate 2, figure 3). The veinlets cut across microcline grains or other plagioclase grains. A third variety of plagioclase is poikilitic, containing quartz and plagioclase. For the most part, this plagioclase is massive, anhedral, exhibits sieve texture, lacks twinning, and is often interstitial with lobate edges. It appears similar to some of the microcline grains (plate 3, figure 1). The vein fillings and massive plagioclase could have formed in a later stage during the cooling history of the pluton, or during a later time of alteration.

A fourth variety of plagioclase is unique to the Capirote pluton. (The other physical types of plagioclase can also be found in the Ladron pluton.) This plagioclase has a texture (plate 4, figure 1 & 2) that appears to result from replacement of microcline. Cataclastic textures are rather common where it is found. The highly albitized samples are almost entirely composed of plagioclase that exhibits this texture. There seem to be stages of this replacement texture: 1) coarsely perthitic microcline, sometimes surrounded by small plagioclase (± quartz) crystals (plate 4, figure 1); 2) crystals of albite and a few

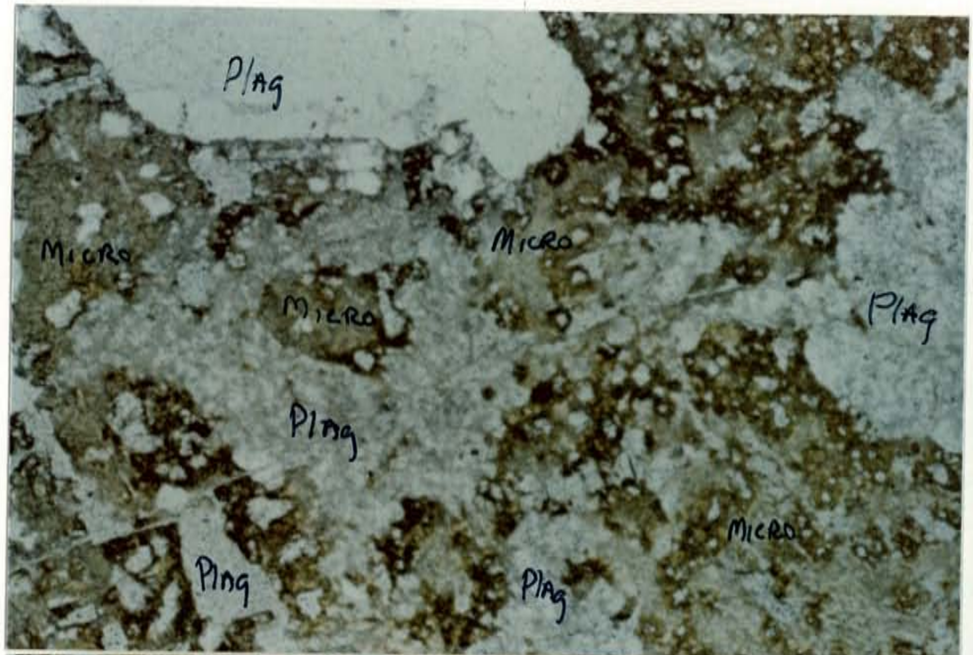


Figure 1
Capirote pluton, LD 89
massive appearing plagioclase and microcline with sieve texture
uncrossed polarizers
40x

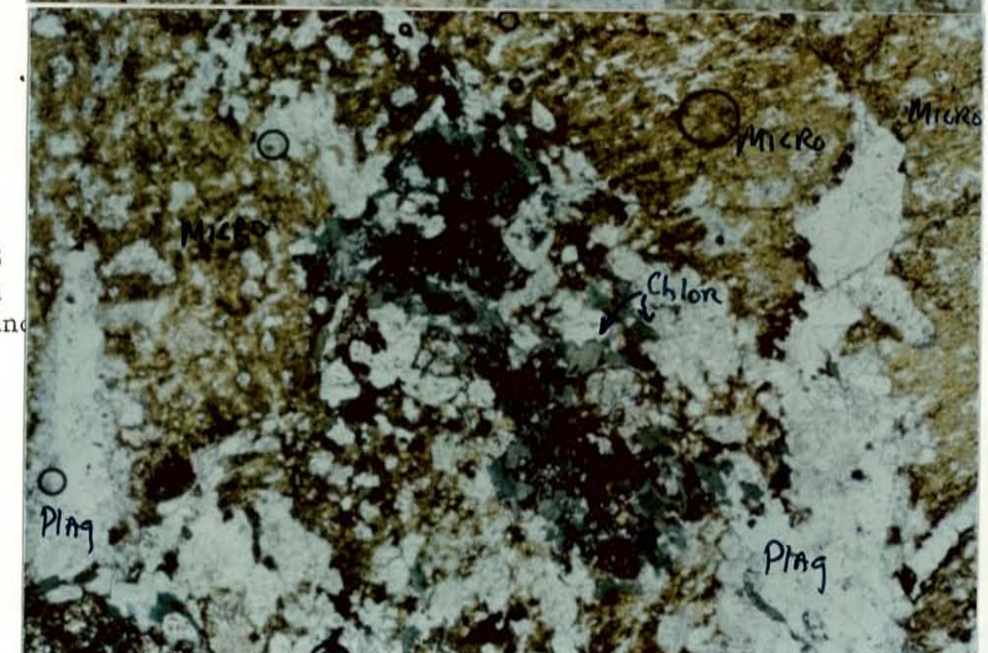


Figure 2
Capirote pluton, LD 108
remnants of mica with chlorite, sphene, and magnetite
uncrossed polarizers
40x

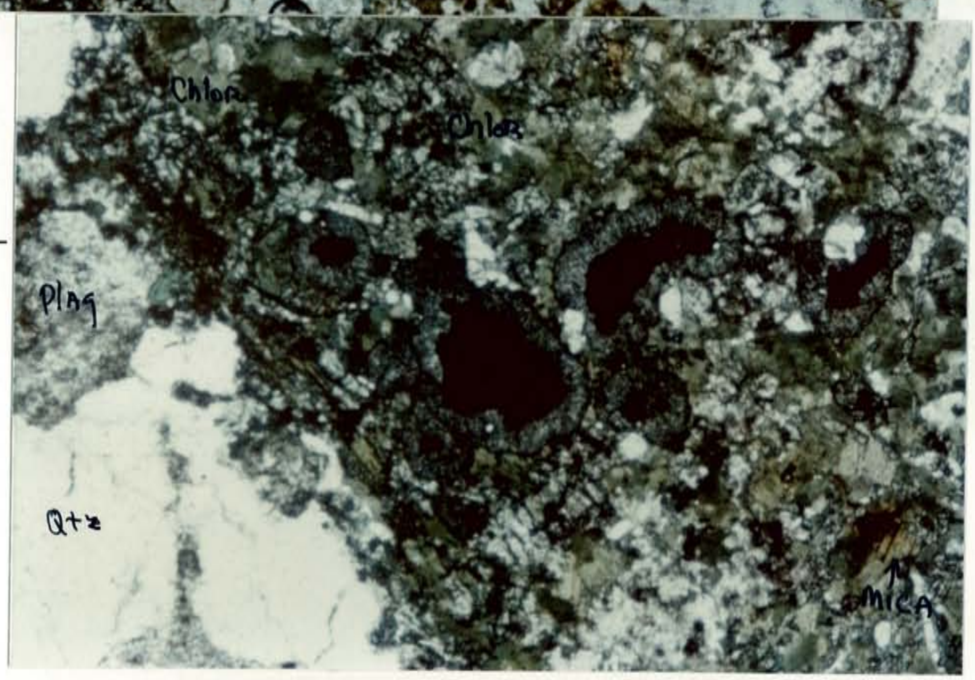


Figure 3
Capirote pluton, LD 93
magnetite surrounded by sphene; note chloritization
uncrossed polarizers
64x

Plate 3

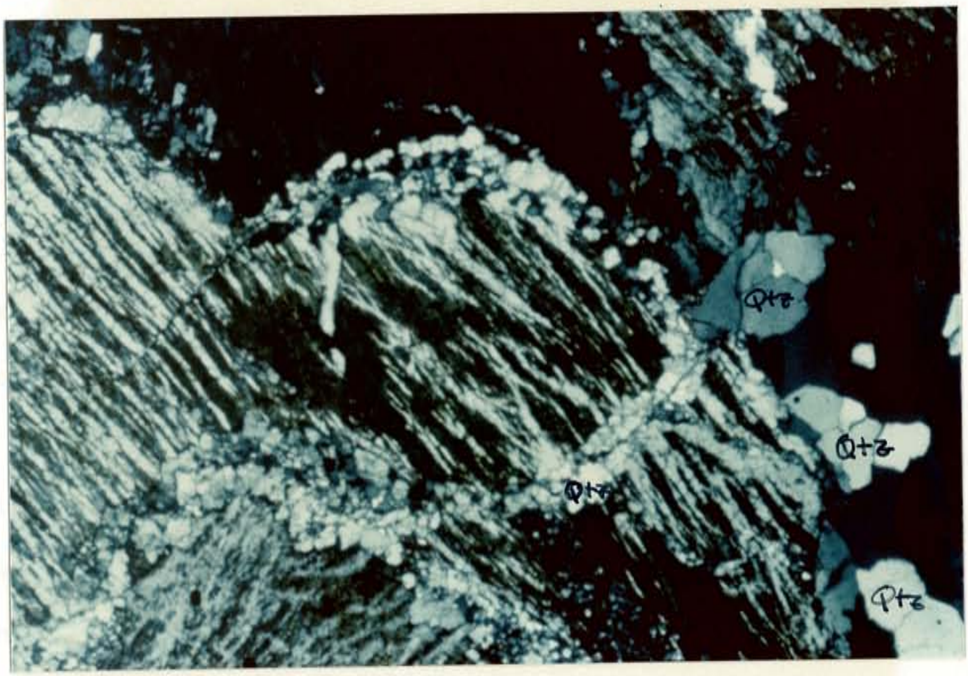


Figure 1
Capirote pluton, LD 101
braided perthite with albite and quartz filling borders around the microcline
crossed polarizers
40x

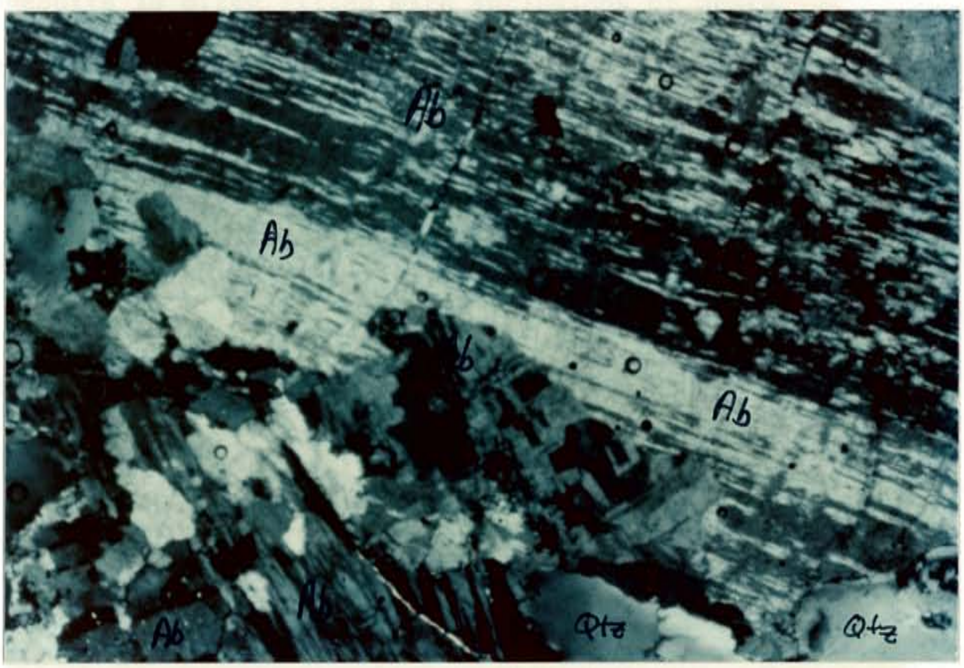


Figure 2
Capirote pluton, LD 99
altered Capirote
albite has replaced the microcline
crossed polarizers
40x

tiny stringers of microcline; and 3) completely albitized rock (plate 4, figure 2). The coarsely perthitic microcline (plate 4, figure 1) surrounded by plagioclase crystals resembles rapakivi texture; however, whether it has the same origin as rapakivi texture is questionable. The texture is of local extent in the pluton; quartz sometimes is present as part of the border of the grains and some cross-cutting veins are filled with the same type of plagioclase as the rim.

A series of replacement textures is suggested for the rocks of plate 4 which represent the albitization of the Capirote pluton. The average composition of the plagioclase was determined to be An_{12} for the unaltered facies, An_{14} for one sample of the altered facies, An_5 for a sample of the altered facies that is highly albitized, and An_{20} for one sample of the granophyric facies. The primary plagioclase of the Capirote quartz monzonite is often filled with inclusions of dusty magnetite and some apatite needles. Plagioclase of the granophyric facies contains only a small number of such inclusions.

Twinning of the first two types of plagioclase is poorly developed. Twinning is lacking in the latter two plagioclase varieties discussed above. The following discussion of twins refers to both types of twinned plagioclase within the Capirote pluton unless specified otherwise. Albite twins are most common, but often the twins do not extend throughout the grains. This twinning is best expressed in small plagioclase crystals in veinlets. Crystal aggregates, with each crystal having twins at right angles to adjacent crystal twinning, are found in some samples of the unaltered facies. Carlsbad twins are not found as frequently as the albite twins. Faint normal zoning occurs in the first type of plagioclase grains. Oscillatory zoning is lacking. Myrmekite is found within plagioclase grains, sometimes when in contact with microcline, The granophyric facies contains interstitial granophyre and some myrmekite (see granophyric intergrowth, page 41).

Mechanical deformation is refected in some plagioclase grains. Examples of deformational textures are found throughout the Capirote pluton. Examples are bent and faulted crystals, undulatory extinction, deformed twin planes, interwoven grain boundaries and crushed edges. Except in the granophyric facies, evidence for replacement is found in many of the feldspars of the Capirote pluton. There is a close relationship between plagioclase and microcline. Sometimes within the same thin section, both microcline replacing plagioclase and plagioclase replacing microcline are noted. Alteration products of both sericite and saussurite are found throughout the Capirote quartz monzonite. Saussurite is found concentrated along twin planes.

Microcline

The crystal outlines of microcline in all of the Capirote quartz monzonite are subhedral to anhedral. The microcline characteristic of the altered and unaltered Capirote is massive, 2-4 mm in average dimensions, coarsely perthitic, and sometimes exhibits sieve textures and lobate margins. This microcline is closely associated with plagioclase of similar texture. Some larger, earlier formed grains of microcline with partial crystal outlines are also present. These crystals contain grid-iron and Carlsbad twins, and are sometimes coarsely perthitic and/or poikilitic, enclosing plagioclase and quartz. The granophyric facies commonly contains subhedral grains of microcline, 2-3 mm, that are surrounded by granophyric intergrowth. The albite within the perthitic microcline varies from braided, to veinlets, to irregular blebs. Replacement is evident in grains exhibiting a pseudo-patched perthitic texture. The enclosed plagioclase crystals contain twins oriented in the same direction. Most of the perthite observed consists of microcline in the approximate ratio of 5:1. This ratio progressively increases in plagioclase in those samples enriched in later albite. Sieve texture is common in the altered and unaltered facies and less common in the granophyric facies. Included within the sieve structures are microcline, quartz and sometimes plagioclase. Microcline, exhibiting sieve texture, is generally untwinned. Granophyric intergrowth is an important feature of the granophyric facies but is also found in several samples of unaltered Capirote quartz monzonite. The samples of the unaltered facies are from an outcrop about 1 km west of the granophyric facies. A detailed description of this intergrowth is given later.

Mechanical deformation textures in the microcline include irregular borders and granulated edges. These textures are not as well expressed as they are in the quartz and plagioclase.

Microcline is a significant interstitial mineral in all facies of the Capirote quartz monzonite. The texture is more massive in the interstitial grains and is similar to the lobate grains described on page 39. Fracture fillings of microcline cut across grains of older plagioclase and microcline in the Capirote pluton. The interstitial microcline and fracture fillings could have resulted from late stage solutions in the development of the pluton or from later alteration. A white powdery substance forms a very thin alteration surface on the microcline grains.

Quartz

All of the Capirote quartz monzonite contains subhedral to anhedral composite grains of quartz. Sometimes the quartz aggregates have a lenticular shape indicative of later deformation. When this shape is present, the grain boundaries are highly sutured and some mortar texture is developed. Secondary quartz veins are abundant in the Capirote pluton. All of the quartz is very clear with only occasional trains of inclusions. These inclusions follow crystal borders and cross-cut grains of quartz. For the most part, other inclusions of tiny rutile needles, apatite, zircon and tourmaline are rare. In a few thin sections from the LD 90 series, the quartz crystals are riddled with small inclusions.

Mechanical deformation features such as undulatory extinction and irregular grain boundaries are found in all of the rock samples examined. More intense deformation features such as sutured grain boundaries, mortar texture, and elongated grains and aggregates are less common. Samples of the altered and granophyric facies exhibite the most extensive development of deformational features.

Granophyric Intergrowth

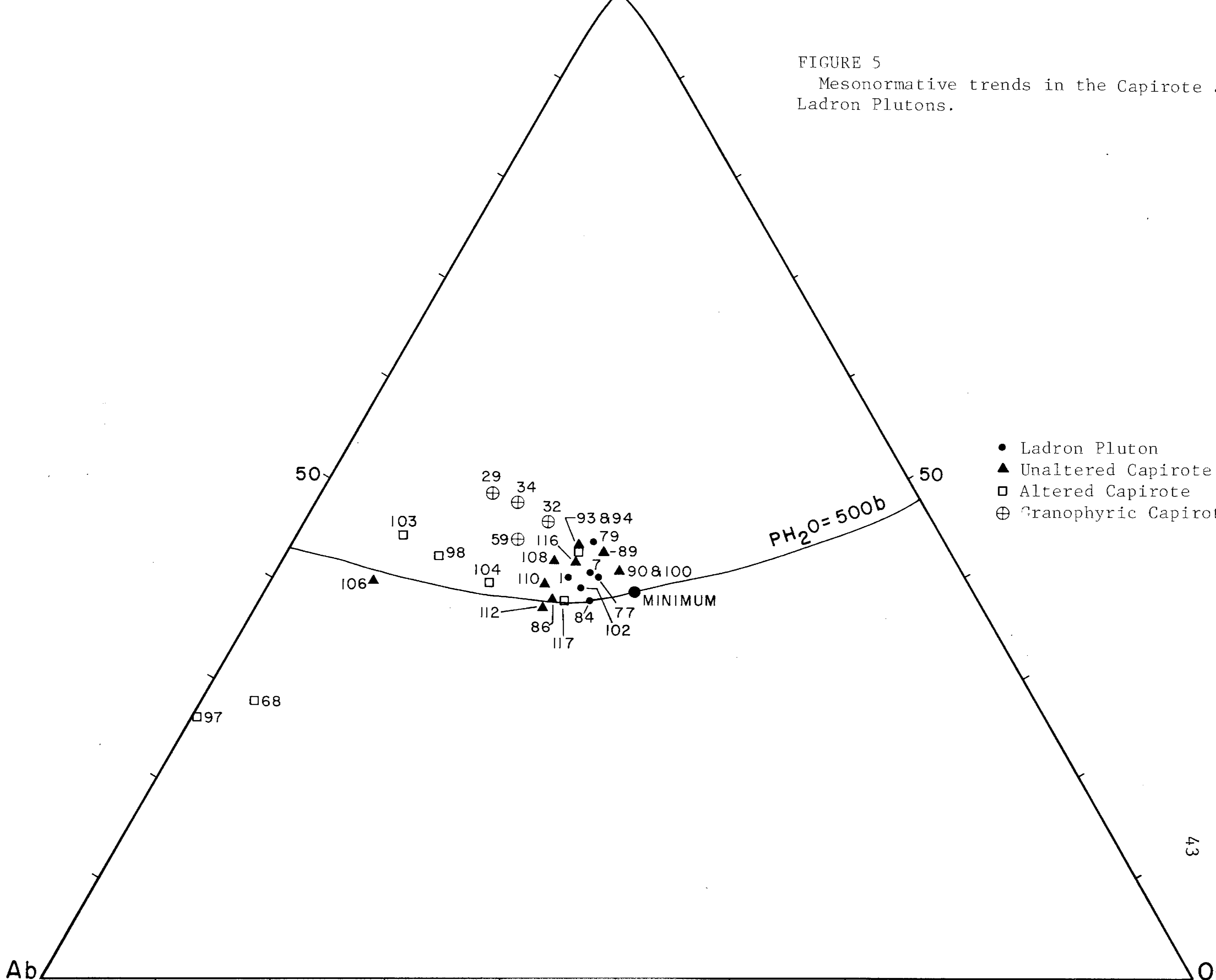
Modal estimates of three thin sections and X-ray fluorescence data on four granophyric facies samples are listed on Table 7 and Table 10. The values are graphically shown on figures 4-7. Fine grained (1-2 mm)

TABLE 10. MAJOR ELEMENT CONTENT OF THE GRANOPHYRIC FACIES OF THE CAPIROTE QUARTZ MONZONITE

Oxide (weight percent)	Rock Samples					
	LD29	LD32	LD34	LD59	$\overline{X}$	STD
SiO_2	77.90	77.90	78.90	77.60	78.10	0.50
TiO_2	0.18	0.17	0.16	0.18	0.17	0.01
Al_2O_3	12.60	12.60	12.30	12.10	12.40	0.21
Fe_2O_3	1.49	1.14	1.00	1.59	1.30	0.24
MgO	0.40	0.11	0.10	0.20	0.20	0.12
CaO	0.33	0.29	0.27	0.36	0.31	0.03
Na_2O	4.03	3.87	3.92	4.08	3.97	0.08
K_2O	2.57	3.42	2.85	3.40	3.06	0.36

$\overline{X}$ = Mean
STD = Standard Deviation (see Table 5)

FIGURE 5
Mesonormative trends in the Capirote and Ladron Plutons.



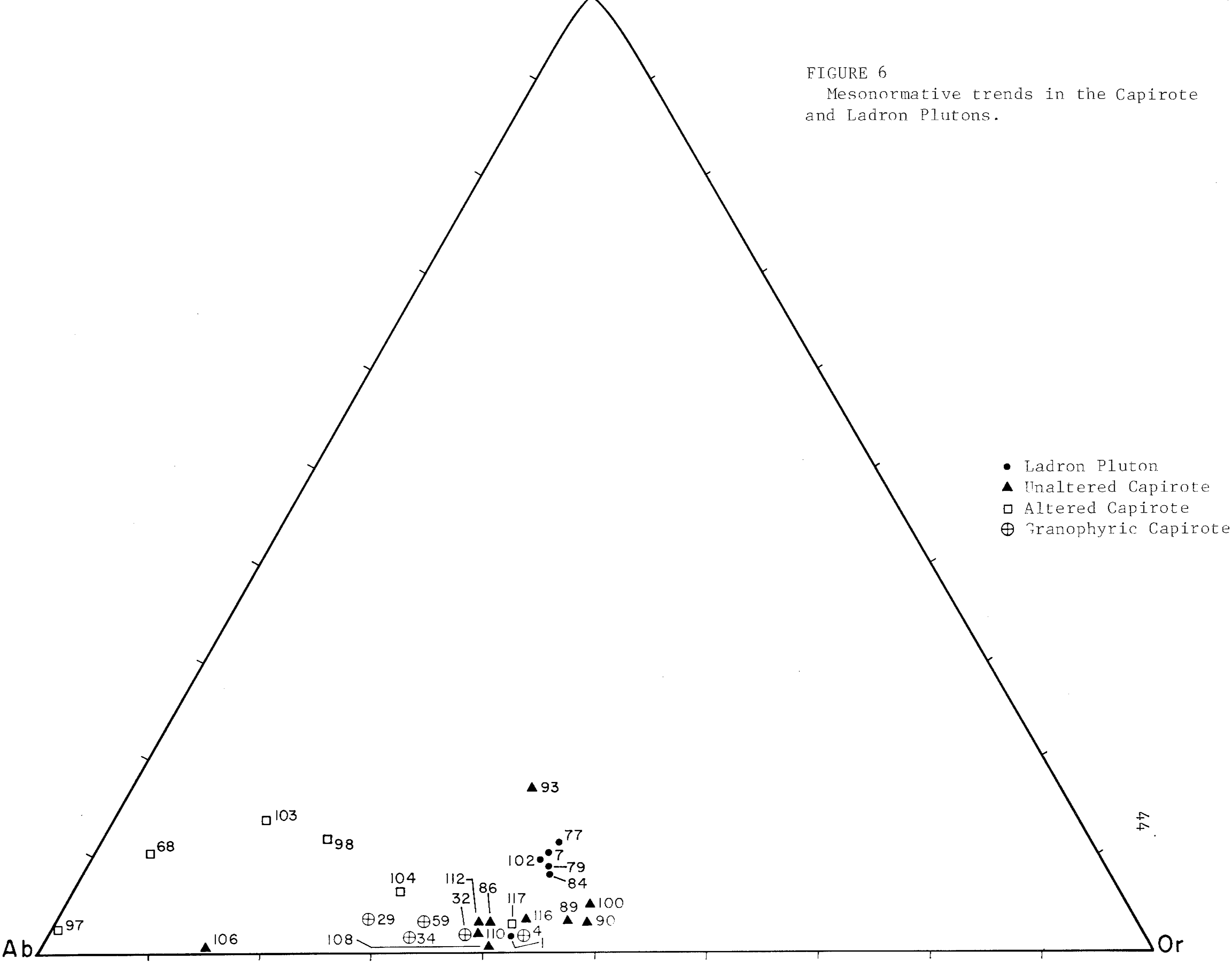
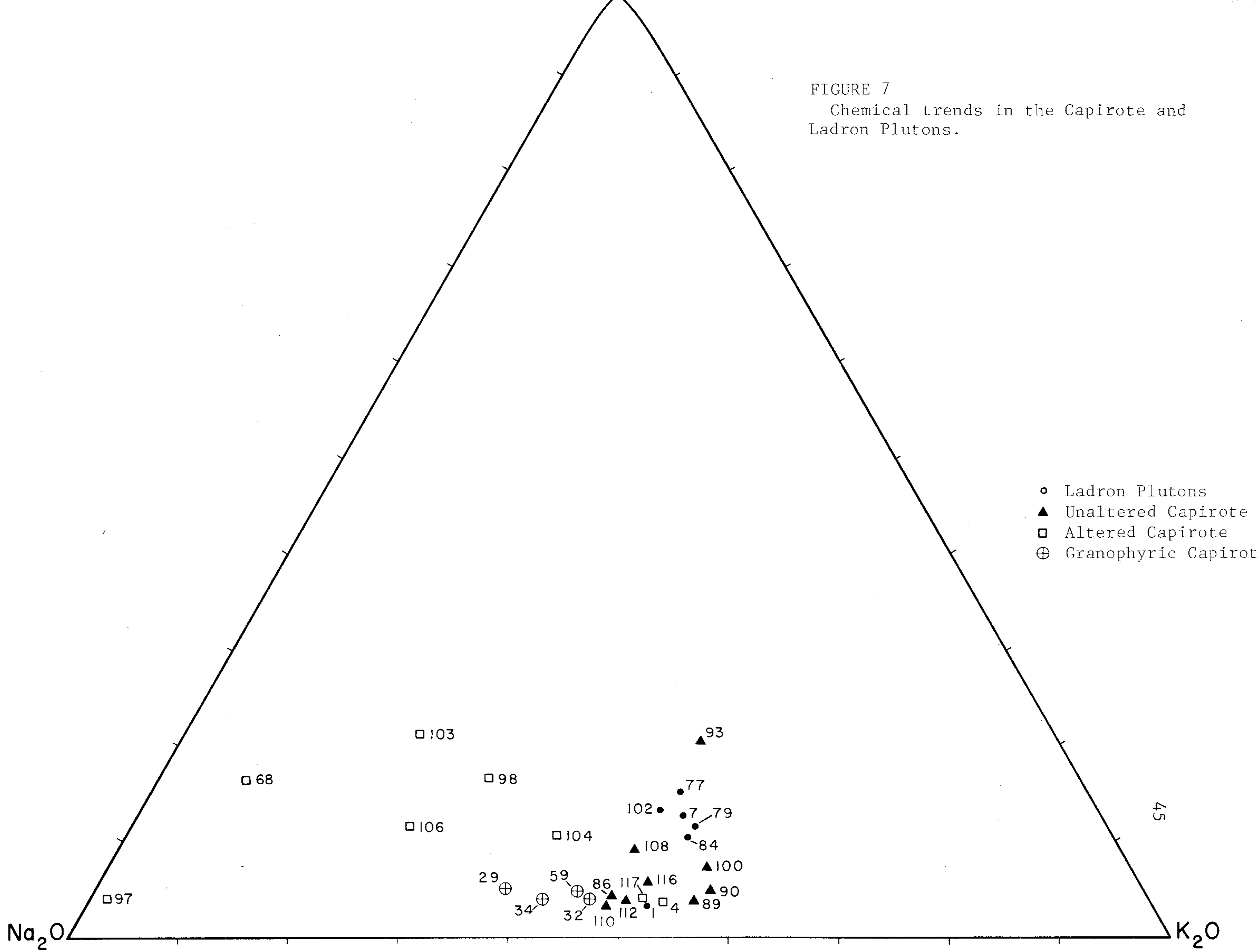


FIGURE 6
Mesonormative trends in the Capirote and Ladron Plutons.

FIGURE 7
Chemical trends in the Capirote and Ladron Plutons.



intergrowths of quartz, K-feldspar, and some sodic feldspar fill interstitial areas of the granophyric facies. LD 96, 92, and 93 of the unaltered and coarse-grained facies also have some intergrowths. The locations of the samples given and of the granophyric facies are on the geologic map (figure 2a). The locality of the unaltered facies containing granophyric intergrowths is just west (approximately 1 km) of the discontinuous outcrop of the granophyric facies. Both outcrops are in contact with the older volcanic unit.

The granophyric intergrowths incorporate larger quartz and/or plagioclase grains, and occasionally surround large microcline crystals. The intergrowths seem to utilize the larger grains as growth nuclei. Optically continuous quartz often radiates outward from the central grains (plate 2, figure 1). Sometimes it is not possible to identify individual feldspars in thin section. Twinning is absent from both the micrcoline and plagioclase within the intergrowths. The most abundant feldspar of the intergrowth is K-feldspar. The crystallographic orientation of both quartz and feldspar are independent of each other.

The intergrowths show some evidence of mechanical deformation. Some samples of the granophyric facies show a linear parallelism of the major mineral constituents. The granophyric intergrowth appears free of inclusions, although sericite is a common alteration product of the plagioclase within the intergrowth and is often an interstitial mineral. The intergrowth is later than the larger grains, but it is a primary constituent of the rock.

Biotite

The biotite within the Capirote quartz monzonite has corroded crystal outlines. It is always associated with its alteration product, chlorite. The biotite is largely an interstitial mineral. It is pleochroic, exhibiting colors of dark to honey brown, and is often interwoven, producing a braidlike texture. The laths are generally from 2 to 4 mm in length. Deformational structures are not well expressed by the biotite because most of the grains are highly altered. Biotite is found included within the second-stage microcline. Experimental work by Maaloe and Wyllie (1975) suggests a 2.5-20 percent range of water content for plutons in which biotite crystallized before the microcline. Some of the biotite is found as numerous short (less than 1 mm) stubby laths suggesting recrystallization. This was perhaps caused by heat from the intrusion of the Ladron quartz monzonite.

Chlorite, titaniferous magnetite, epidote, sericite, sphene, and traces of hematite and limonite are commonly found together as the result of biotite alteration. All of the major alteration products are found as fine-grained aggregates with the exception of chlorite, which is often in a lath-like form. The alteration products conceal any identifiable primary inclusions.

Magnetite

In all facies of the Capirote quartz monzonite there are euhedral to anhedral crystals of titaniferous magnetite. The large well formed crystals are approximately 1 mm across and sometimes found in local concentrations, within the pluton. These grains are larger than the magnetite formed from the alteration of biotite, and are isolated from the associated biotite alteration products. The magnetite grains often have hematite and leucoxene alteration products. Some samples of the coarse grained facies have magnetite with sphene coronas. The sphene grew at right angles to the margins of the magnetite (plate 3, figure 3). Magnetite is found within plagioclase, microcline, and sphene.

Epidote

Veins of massive granular epidote are found throughout the Capirote quartz monzonite. The veins generally range from 3-8 mm in thickness. The epidote veins indiscriminately cut across all the major minerals in the rock. Some of the epidote found in veins is elongated and in fanlike clusters. Minor calcite is sometimes associated with the veins containing epidote. The origin of this epidote, whether it is hydrothermal or a later metamorphic event, is questionable. Secondary epidote from the alteration of biotite is quite common also. This epidote, like some of the vein filling, is massive and granular in habit. Zoisite is present in sample LD 103 as a vein filling 1 mm in thickness.

Sphene

Euhedral to subhedral sphene is found in all four facies of the Capirote pluton. It is approximately 1 to 2 mm in length. The crystals are medium to dark brown and some larger ones reflect a faint zonation, the center having an altered appearance and the margins darker looking. Larger crystals contain inclusions of subhedral zircon and titaniferous magnetite. Leucoxene, the alteration product, is always associated with sphene. Sphene is also found included in microcline grains. Secondary sphene, as mentioned earlier, is present as an alteration product of biotite. It is very common throughout the Capirote quartz monzonite.

Allanite

Reddish brown allanite, less than 2 mm in length, is in all but the granophyric facies of the Capirote pluton. The crystals are generally anhedral but a few are euhedral. Zoning is sometimes found. The zoned grains contain darker euhedral cores and rounded outer margins. Inclusions of euhedral zircon are rare. Allanite can be found within grains of plagioclase and microcline. Epidote is commonly found around the margins of allanite grains. Sample LD 108 contains sphene growing at right angles around allanite and titaniferous magnetite.

Zircon

A small percentage of zircon, with crystals less than 0.5 mm in length, is present in all but the granophyric facies of the Capirote quartz monzonite. The zircons are euhedral to anhedral. The anhedral grains have extinction parallel to the long dimension of the crystal. The color of the zircon grains ranges from brown (inclusion poor varieties) to very pale green (inclusion-rich varieties). Inclusions within the zircons are both needle-shaped and round; all are too small for identification. Zircons are found as inclusions in all the major minerals and also as matrix minerals.

Other Accessory Minerals

Apatite grains can be found within some of the plagioclase and quartz grains. Some crystals are interstitial, but these are rare. This mineral is found as acicular prisms with hexagonal cross sections.

Trace amounts of massive interstitial calcite are found in samples LD 68, 78, 87, 116, 117 and 119. The calcite is present as secondary vein fillings, sometimes associated with epidote.

Fluorite is present in some of the LD 90 series rock samples. It appears primary and is not associated with vein fillings. LD 96 contains a good example of the subhedral fluorite (plate 2, figure 2). The fluorite is only assciated with rocks containing granophyric intergrowth. It is clear and less than 1 mm in length. The fluorite is found as an independent late stage mineral, not included in the other major minerals.

Crystallization Sequence

The Capirote pluton has a two stage history: magmatic and alteration. Albite is the dominant secondary mineral but extensive deuteric alteration of the biotite is also an important result of the alteration stage. Albite is a late stage replacement mineral in this pluton. The melt was enriched with Na and K as a result of the crystallization process within the pluton. Orville (1963) studied the system $KAlSi_3O_8$-$NaSi_3O_8$-NaCl-KCl-H_2O. In comparing crystal-melt equilibria, he determined the fractionation of alkalies between the fluid phase and crystalline phase of feldspar is dependent on temperature. The cooler portions of plutons are enriched in K and the warmer portions enriched in Na, replacement being the mechanism of enrichment.

Three factors may have played a role in the albitization of the Capirote pluton: 1) The areas in which albite is dominant were warmer portions of the pluton; 2) the intrusion of the Ladron quartz monzonite reheated these areas causing the K/Na ratio to drop; and, least likely, 3) the possibility that it was caused by a later thermal metamorphic event (perhaps Tertiary in age). The texture of the albitized rocks appears to be the result of replacement and not primary crystallization (plate 4, figures 1 & 2). This replacement texture becomes a more dominant feature in samples closest to the Ladron pluton.

Based on crystal shape, included minerals, cross-cutting relationships, and replacement textures mentioned earlier in the text, the proposed crystallization sequence is given in Table 11.

Bulk Composition

Results from X-ray fluorescence analysis of ten samples from the unaltered facies, seven from the altered facies and four from the granophyric facies of the Capirote quartz monzonite are listed on Tables 10, 12, and 13. The Capirote quartz monzonite is distinguished from the Ladron quartz monzonite in that it is:

1. Lower in Al_2O_3, CaO, and K_2O;
2. The MgO content is less variable; and
3. The Na_2O content is higher.

The altered facies can be distinguished from the unaltered facies of the Capirote pluton by a higher Na_2O content, and lower K_2O and Fe_2O_3 content. The granophyric facies, based on only three points, appears similar to the other facies of the Capirote pluton in MgO and CaO. It lies between the altered facies and unaltered facies in Na_2O and K_2O contents.

TABLE 11. SEQUENCE OF CRYSTALLIZATION IN THE CAPIROTE PLUTON

	Magmatic (first stage)	Alteration (second stage)
Apatite Zircon Allanite Sphene Magnetite	__________. . . . .?	Sphene . . . . .__________? Magnetite . . . .__________?
Plagioclase	oligoclase	albite ____________________
Microcline	________	____________ . . . . .?
Biotite	____.	chlorite titaniferous magnetite epidote sericite sphene (hematite & limonite)
Quartz	____________________	____________________
Epidote		________. . . . .
Fluorite	________	

TABLE 12. MAJOR ELEMENT CONTENT OF THE CAPIROTE QUARTZ MONZONITE SAMPLES

Oxide (weight percent)	Rock Samples											
	LD86	LD89	LD90	*LD93	LD100	LD106	LD108	LD110	LD112	LD116	$\overline{X}$	STD
SiO_2	76.50	77.80	77.10	71.10	77.70	74.70	75.30	76.90	75.20	76.00	75.80	1.90
TiO_2	0.18	0.19	0.13	0.62	0.16	0.28	0.32	0.23	0.29	0.27	0.27	0.13
Al_2O_3	13.70	12.90	13.10	13.80	12.70	13.70	12.80	12.80	13.20	13.00	13.20	0.39
Fe_2O_3	0.36	0.10	0.52	4.25	0.10	1.44	2.41	0.95	1.91	1.86	1.39	1.23
MgO	0.10	0.22	0.11	0.43	0.05	1.09	0.10	0.11	0.15	0.07	0.24	0.30
CaO	0.39	0.32	0.41	1.84	0.64	0.92	0.80	0.29	0.33	0.48	0.64	0.45
Na_2O	4.21	3.44	3.41	3.08	3.39	5.29	3.75	4.22	4.20	3.70	3.87	0.60
K_2O	4.06	4.53	4.72	4.38	4.76	2.08	4.02	4.00	4.22	4.12	4.09	0.72

* = Coarse Facies
$\overline{X}$ = Mean
STD = Standard Deviation (see Table 5)

TABLE 13. MAJOR ELEMENT CONTENT OF THE ALTERED FACIES OF THE CAPIROTE QUARTZ MONZONITE

Oxide (weight percent)	Rock Samples								
	LD4	LD68	LD97	LD98	LD103	LD104	LD117	$\overline{X}$	STD
SiO_2	77.90	75.10	75.20	74.90	77.10	75.00	76.80	76.00	1.10
TiO_2	0.12	0.32	0.21	0.26	0.27	0.26	0.12	0.22	0.07
Al_2O_3	12.70	14.10	14.90	13.50	12.30	13.60	13.30	13.50	0.80
Fe_2O_3	0.44	0.80	0.20	2.14	0.31	1.51	0.45	0.84	0.67
MgO	0.10	0.01	0.10	0.14	0.97	0.50	0.11	0.28	0.32
CaO	0.28	1.56	0.40	1.40	1.81	0.88	0.36	0.96	0.59
Na_2O	3.71	7.36	8.38	4.63	4.92	4.49	4.08	5.37	1.65
K_2O	4.25	0.25	0.11	2.53	1.82	3.26	4.28	2.36	1.60

$\overline{X}$ = Mean
STD = Standard Deviation (see Table 5)

Mesonormative data plotted on the phase equilibria triangles Q-Ab-Or and An-Ab-Or (figures 5 and 6, pages 43 and 44) show a number of trends and distinctions. The trend of the altered Capirote quartz monzonite towards greater albite content is graphically expressed on the two triangles. The granophyric facies is higher in Q than the other facies, and intermediate in Ab between the unaltered and altered facies. Points for the unaltered facies of the Capirote quartz monzonite cluster around the low temperature trough of the Q-Ab-Or triangle at 500 bars P_{H_2O}(Tuttle and Bowen, 1958).

A distinction between the Capirote pluton and the Ladron pluton is shown on the An-Ab-Or plot (figure 6). The Capirote quartz monzonite is lower in An content than the Ladron quartz monzonite. LD 93 and 106 are not considered representative samples of the Capirote pluton. These two samples diviate from the other Capirote samples onthe mesonormative plots. Perhaps the more recent faulting formed channels for solutions to alter the composition of the two samples. The chemical differences may be due to some epidote veins found within LD 93 and 106. The exact reason for the discrepancy is uncertain but it raises serious doubts of the validity of the samples.

The CaO-Na_2O-K_2O triangular diagram (figure 7) shows chemical trends. in general, the rocks of the Capirote quartz monzonite contain Na_2O and K_2O in the approximate ratio of 1:1 and are low in CaO. Figure 8 shows the distinct trend of the altered facies towards Na_2O enrichment ending at LD 97. The granophyric facies is intermediate between the unaltered and altered facies and rather low in CaO content. If microscopic examination could determine all of the secondary plagioclase, an attempt would be made to show a relationship between the secondary plagioclase and Na_2O content of the rock samples. Often there is a slight difference between the primary and secondary plagioclase. This difference is not always recognizable using a petrographic microscope. A detailed X-ray study might clarify the difference between primary and secondary plagioclase. An attempt was also made to demonstrate a relationship of epidote versus CaO concentrations in the rock samples. A definite correlation could not be established.

LADRON QUARTZ MONZONITE

General Character

The Ladron quartz monzonite, the youngest Precambrian pluton in the area, crops out in the northern and eastern portions of the Ladron Mountains (figure 2a). The most extensive exposure of the pluton ($\sim$20 km^2) is just east of Ladron Peak. This intrusive forms massive, steep and jagged hills; it does not weather readily and often shows a spheroidal or knobby weathering habit (plate 5, figure 1).

The Ladron intrusive is quite uniform in composition (Tables 9 and 15) and texture. The main body of the pluton consists of light brown to pink equigranular rocks with 3-5 mm grain size. There is also a late stage white facies with a variable grain size ranging from 1 to 10 mm. The large variation of grain size may be due to crystal growth influenced by concentrations of volatile elements. Both facies are mineralogically similar and their contacts are gradational. The white facies crops out in the eastern portion of the thesis area (figure 2a), and can easily be seen around the Brown (Lazy C Bar J) Ranch. Essential minerals are aplitic plagioclase, quartz, perthitic microcline, muscovite and biotite. The latter two minerals vary considerably in amount within the pluton. Epidote veins approximately 3-5 mm in thickness can be found but are not as common as in the Capirote pluton. Rocks of the Ladron pluton lack foliation and have equigranular textures. Cenozoic faulting and metamorphism have caused some cataclastic textures in local areas within the pluton.

Figure 1. Spheroidal weathering habit of the Ladron Pluton. Photo taken in the canyon directly south of Monte Negro location.

Figure 2. White facies of the Ladron pluton within the Capirote pluton.

Figure 3. Small rounded amphibolite inclusion within the Ladron pluton.

Contact Relationships

Contact relationships are generally well exposed. Contacts with the older Precambrian rock are defined by a sinuous pattern and are sharp, with little change in the country rock. Structural evidence for the Ladron intrusion, such as jointing and periperal cleavage, is best expressed on the ridge outcrop about 1 km SE of Monte Negro. Precambrian metavolcanic rocks are gradational with the Ladron pluton (the transition typically occurs over about 1-2 meters). Enrichment of the country rock with K-feldspar is noted but it is minor relative to the contact of the Capirote pluton with the metavolcanics. The contact of the Ladron pluton with the older Precambrian metamorphics is exposed on the southern margin of the pluton. At this location, the contact is strikingly discordant.

Inclusions

The Ladron quartz monzonite contains few inclusions, some of which are recognized as remnants of the adjacent metasedimentary rocks and metavolcanics. The inclusions (plate 5; figure 3) are usually small, (about 10 to 30 cm in maximum dimension), well rounded to subrounded in shape, and vary from siliceous volcanics to schists to quartzites to amphibolites in composition. The contact of quartz monzonite with the inclusions shows only negligible assimilation.

Aplites, Pegmatites and Quartz Veins Associated withthe Ladron Pluton

A moderate number of aplites are found both within the Ladron quartz monzonite and extending into older metamorphic and metavolcanic rocks. The dikes are composed mainly of quartz, K-feldspar and sodic plagioclase. The aplites generally range from 6 to 20 cm in thickness and extend for several to many tens of meters, with their surface expression sometimes along very straight paths, perhaps following fractures in the country rock (plate 6; figures 1 and 2). The aplites have a grain size of from 1-2 mm but locally contain coarser grained areas with a grain size of 5-7 mm. Sometimes these dikes are found with a zonal arrangement of crystal size increasing inward from the margins of the dike. A few of the zonally arranged dikes are composite, consisting of repeated progressions of grain sizes. The crystals of the aplites and pegmatites are generally subhedral, showing some good crystal faces. Quartz is sometimes found as euhedral prisms. In some localized pegmatite zones, 10 by 10 cm clusters of euhedral (1-4 mm) magnetite crystals occur. The dikes trend in random directions.

Milky quartz veins are most commonly found extending from the Ladron quartz monzonite into the Capirote quartz monzonite. These quartz veins, ranging from 0.3 to 1 m in width and up to 10 m in length, form prominent white knobs and ridges. The contact of the veins with the Capirote pluton is quite sharp, as if the quartz filled in zones of weakness. The quartz veins are probably late phase stringers from the Ladron quartz monzonite. The orientation of aplites, pegmatite veins, and quartz veins is random but the numbers increase in local regions of the pluton and extend into the older Precambrian rocks.

Petrography

Hand Specimens

In hand specimen, the Ladron rocks generally are mottled dark gray and white reflecting biotite and feldspar, or light pink and white

Figure 1.

Figure 2.

Figure 3.

Figure 1. Aplite dikes intruding amphibolite and the Capirote pluton from the Ladron intrusive. The scale of these aplites is shown in Figure 2.

Figure 2. A close view of the aplites.

Figure 3. An "older" amphibolite dike that has been partially granitized and cut by the Ladron pluton.

Plate 6

probably reflecting hematite in the K-feldspar and plagioclase. The white facies is porcelain white both in hand speciman and in outcrop, reflecting the very low amounts of biotite and magnetite and the presence of white feldspar. The weathered surface of the pluton is, in general, white to light brown. Outcrops of the white facies look similar to figure 2 on plate 5. The quartz monzonite is holocrystalline, phaneritic in texture, and consists of subhedral to anhedral grains. It can often be distinquished from the Capirote quartz monzonite by the presence of muscovite.

Modal Analysis

Statistical thin section analysis of 12 rock samples of the Ladron quartz monzonite using point counting techniques are listed on Table 9. Four of the 12 samples are from the white facies. Locations of the rock samples are given on figure 2a. The compositions of the Ladron samples are relatively uniform (Figure 8) with most samples concentrated in a centrally located region of the quartz monzonite field.

Mineral Descriptions

Plagioclase

Subhedral to anhedral crystals of plagioclase average from 1 to 4 mm in length; the larger grains are found in the white facies. The crystals are sometimes found as aggregates. These are considered early in the crystallization sequence because they include only tiny accessory minerals, and are found enclosed by interstial microcline (plate 7, figure 1), quartz, biotite and muscovite. Another less common variety of plagioclase, 1-3 mm in length, is massive, lacks twinning, has lobate

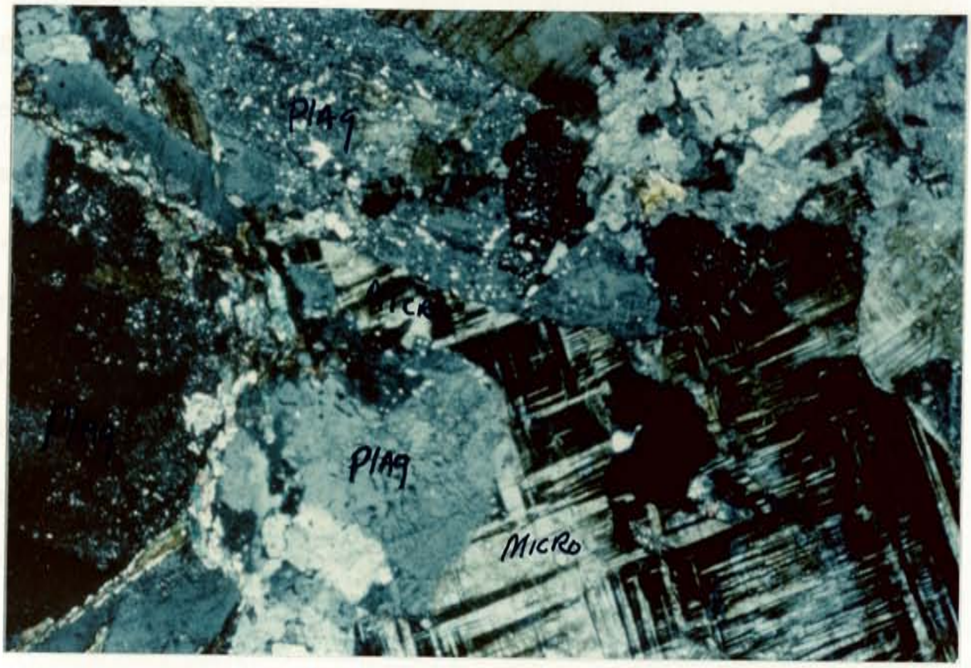


Figure 1.
Ladron pluton, LD 78
interstitial microcline
crossed polarizers
40x

Figure 2.
Ladron pluton, LD 7
oscillatory zoned plagioclase
uncrossed polarizers
40x

margins (plate 8, figure 2), and sometimes is riddled with tiny inclusions. This plagioclase is found replacing microcline and in vein fillings. Because this plagioclase is found replacing better formed crystals of plagioclase and replacing microcline, it is either a product of later crystallization or it formed in a process of late stage alteration. The average composition of plagioclase composite samples was determined to be An_{13} using the semiquantitative X-ray diffraction techniques of Smith and Yoder (1956). Generally the plagioclase of the Ladron quartz monzonite contains tiny inclusions and/or dusty magnetite, apatite needles and some inclusions that are difficult to identify.

Twinning of the plagioclase is poorly developed. Albite twins are most common but carlsbad twins are also found. Often twinning is not uniform throughout the crystals. Zoning occurs in about 20 percent of the total plagioclase. Normal progressive zoning is the most common and sometimes oscillatory zoning is present (plate 7, figure 2). Myrmekite is most often found associated with plagioclase grains in contact with microcline grains.

Mechanical deformation is reflected in a few of the plagioclase grains. The most common deformation features are intercalated grain boundaries and bent crystal laths. The deformation is localized in fault zones. Evidence for replacement, such as lobes of plagioclase encroaching on microcline and vice versa, is found in the Ladron quartz monzonite. Alteration products of sericite and saussurite are present in the plagioclase, sericite being more common.

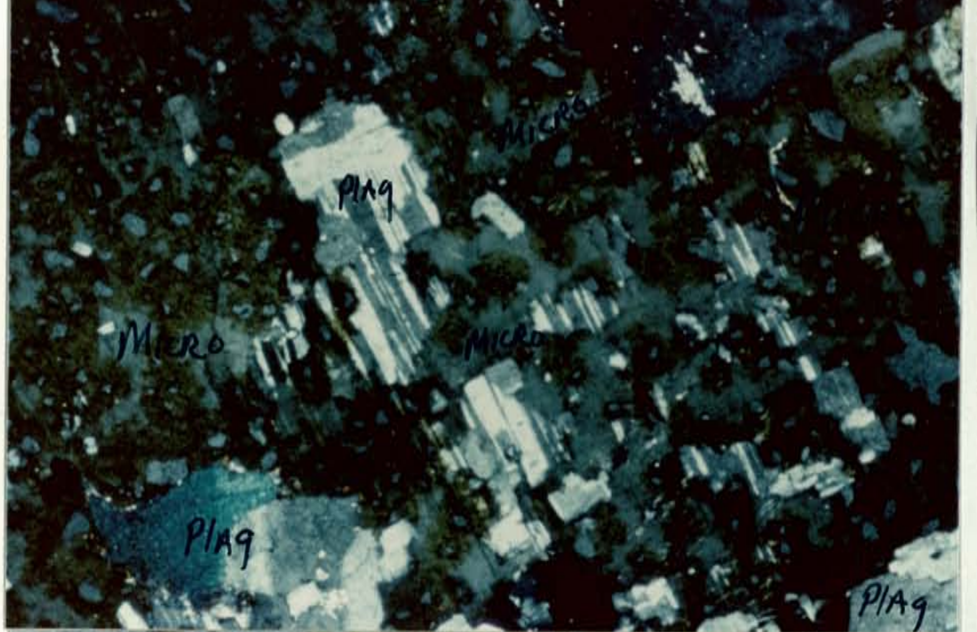


Figure 1.
Ladron pluton LD 80
plagioclase surrounded by microcline
crossed polarizers
40x

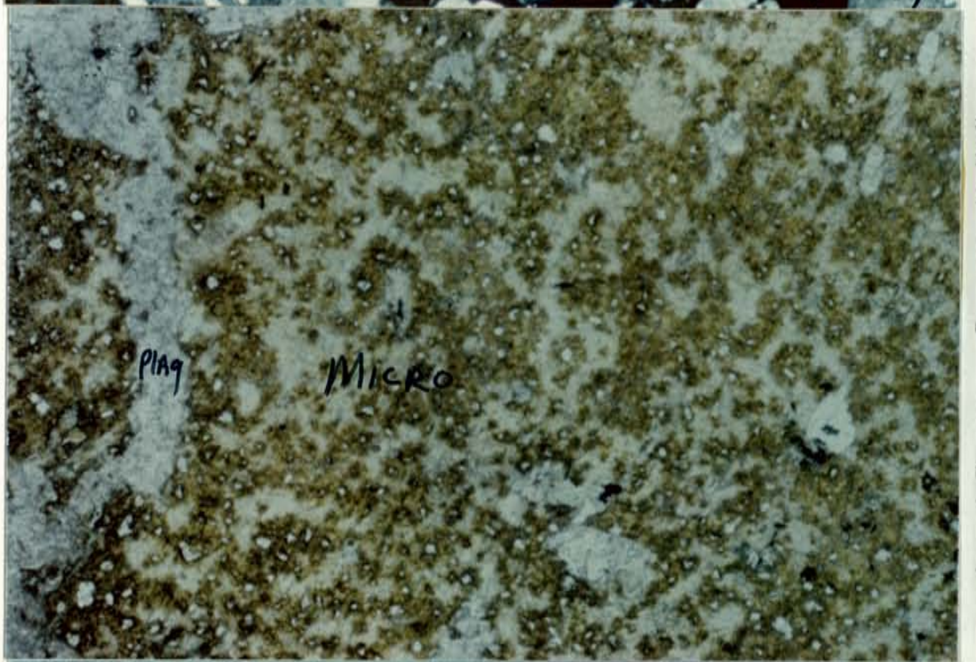


Figure 2.
Ladron pluton LD 1
white facies
sieve textured microcline and massive looking plagioclase
uncrossed polarizers
40x

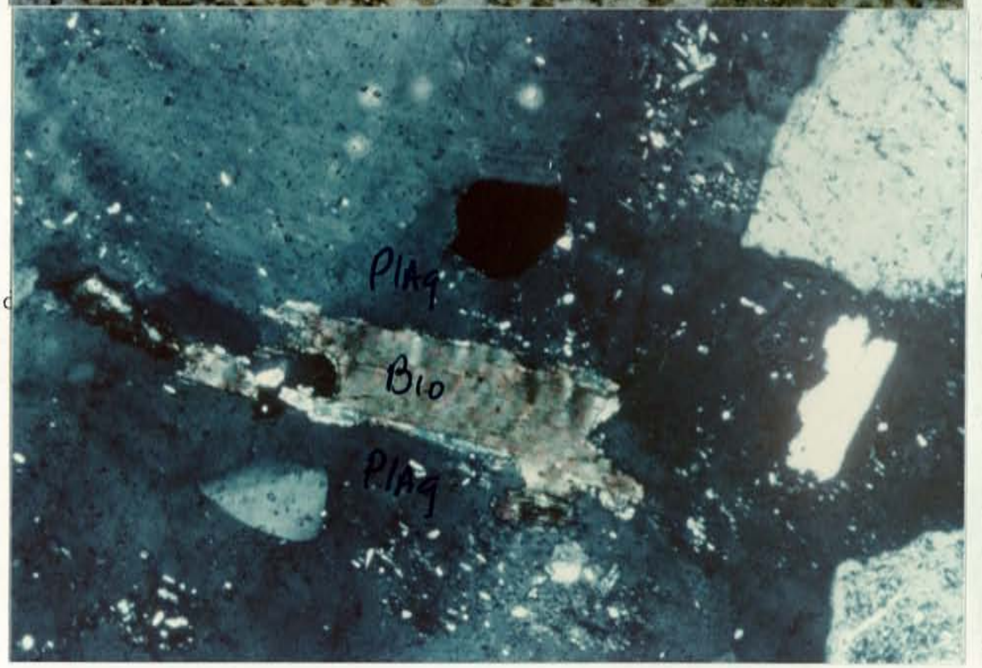


Figure 3.
Ladron pluton, LD 78
biotite and magnetite included within plagioclase
crossed polarizers
160x

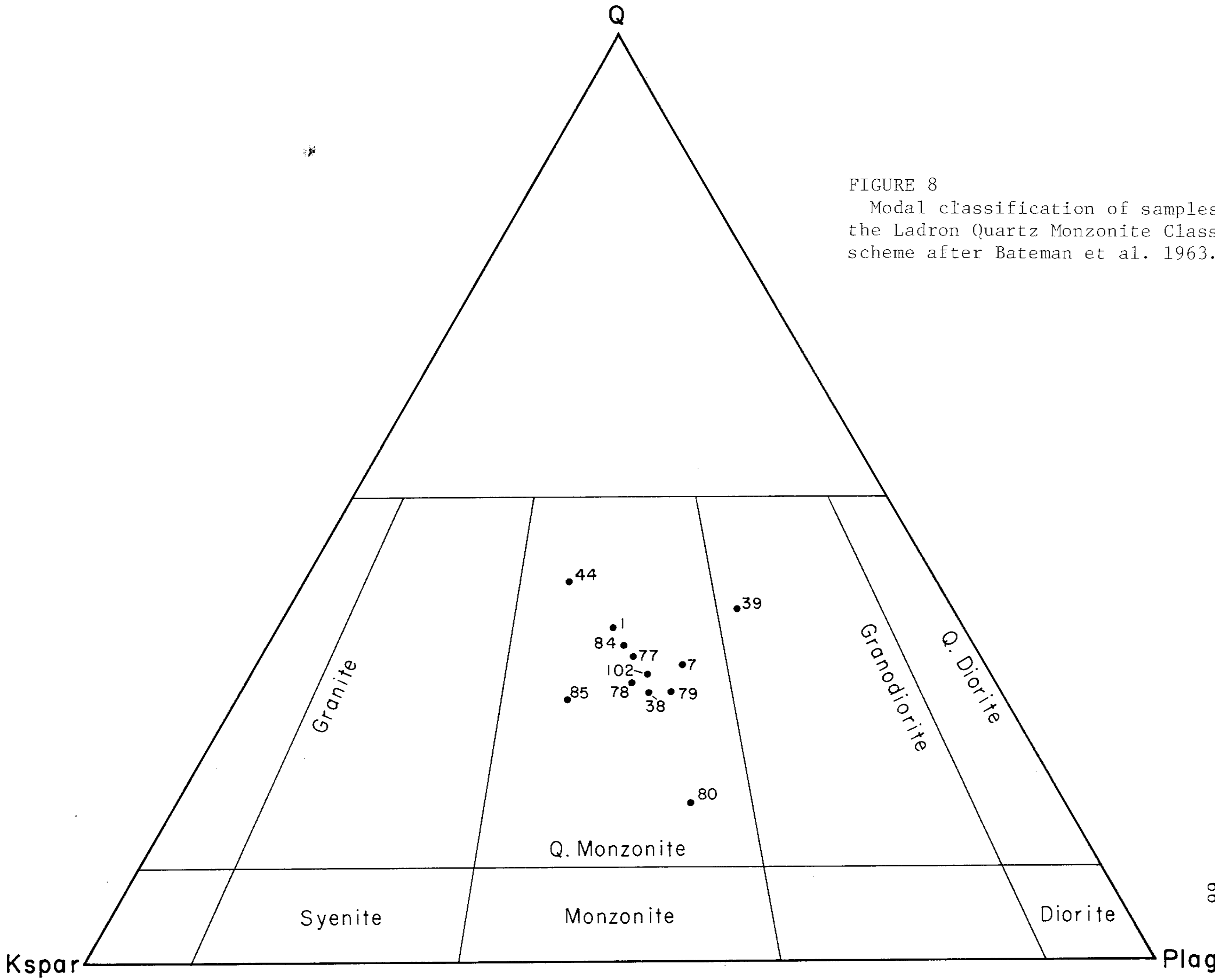


FIGURE 8
Modal classification of samples from the Ladron Quartz Monzonite Classification scheme after Bateman et al. 1963.

Microcline

The Ladron pluton contains subhedral to anhedral microcline crystals 3-7 mm in size and only a few euhedral crystals. Most of the microcline grains are quite heterogeneous in texture. The texture is generally moderately developed hazy gridiron and carlsbad twins, sieve and poikilitic textures. Microcline with a poikilitic texture contains plagioclase (sometimes euhedral), and earlier microcline (plate 8, figure 1), and sometimes biotite. Some microcline has grown at the expense of the plagioclase grains by engulfing them. The microperthite is either braided or patchy. Some of the "patch perthite" contains twinned plagioclase. These small crystals of plagioclase within the micorcline have oriented albite twins and are probably due to the replacement of plagioclase grains by K-feldspar. The "oriented" perthite observed consists of microcline and plagioclase in the approximate ratio of 10:1. Mechanical deformation textures of the microcline in the Ladron pluton include irregular grain borders and granulated edges.

Quartz

The Ladron pluton contains subhedral to anhedral quartz grains 1-3 mm in size. Grain boundaries of quartz are often intercalated. Secondary quartz veins are present but not common. The quartz is often clear, but sometimes contains bubble trains, trains of fine dusty looking inclusions, and rutile needles. Apatite and tourmaline are rare inclusions in the quartz. Mechanical deformation features such as undulatory extinction and irregular grain boundaries are common. More intense deformation features such as sutured and crushed grain boundaries are rare.

Muscovite

Subhedral to anhedral grains of muscovite are generally fresh in appearance and 1-4 mm in size. Muscovite plates are often bent and twisted exhibiting wavy extinction and sometimes corroded edges. Muscovite grains contain inclusions of zircon(?), dusty magnetite, and minor apatite. Sericite is present as an alteration product of plagioclase, intersitially and as vein fillings. Secondary sericite from the alteration of plagioclase often grades into coarser grains of muscovite.

Biotite

The biotite of the Ladron pluton is often found interwoven with muscovite. It sometimes exhibits a braided texture, undulatory extinction, and occurs as large crystals. Pleochroism varies from greenish brown to light brown, olive green to golden yellow and reddish brown to golden brown. Radioactive halos around zircon and allanite (?) inclusions are common. Usually inclusions within the halos are small and, if not zircon, they are difficult to identify. Biotite is present as inclusions in microcline, and is sometimes found surrounded by quartz and included in some plagioclase grains (plate 8, figure 3). Experimental work by Maaloe and Wyllie (1975) suggests a large range water content (2.5-20 percent) for plutons in which biotite has crystallized with the plagioclase but prior to K-feldspar.

Biotite is commonly found with alteration products of chlorite, titaniferous magnetite, sericite, epidote, sphene, and traces of hematite, limonite and leucoxene. These alteration products are sometimes found without the biotite remnants. All of the major alteration products are found as fine-grained aggregates with the exception of chlorite which often forms pseudomorphs after biotite.

Accessory Minerals

Primary magnetite is present as euhedral to anhedral grains, approximately 1 mm across and incorporated in microcline, plagioclase and quartz. Generally the alteration product is hematite, although a few grains have minor white leucoxene alteration. This suggests a titanium content within the magnetite. The dusty magnetite is found as an alteration product of biotite.

Apatite when present is found as euhedral to subhedral prisms with typical hexagonal cross sections. The crystals are always fresh looking and clear. Apatite is found as inclusions in plagioclase and microcline.

Several forms of epidote occur in the Ladron pluton. The epidote is found as 1 to 2 mm long, subhedral to anhedral crystals (plate 9, figures 1 and 2), as grainy aggregates resulting from the alteration of biotite, and as tiny crystals which appear to result from the alteration of plagioclase. Veins of epidote are very rare in the Ladron pluton. Clinozoisite (plate 9, figure 1) with the typical anomalous blue and brown birefringence is sometimes present as 1-2 mm crystals in association with epidote. The grains of clinozoisite are discrete and more massive looking than the epidote. The larger crystals of epidote

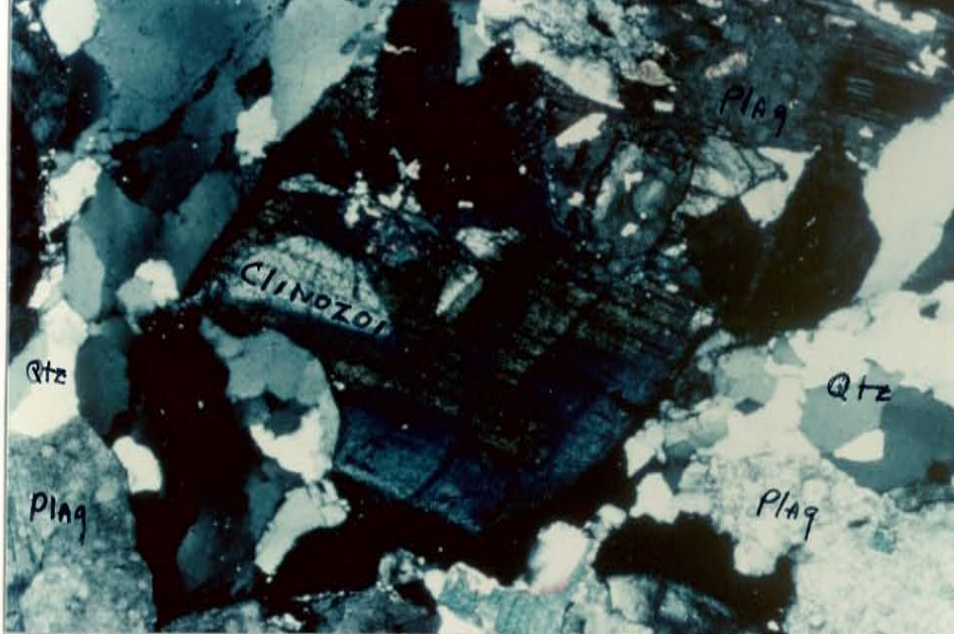


Figure 1.
Ladron pluton, LD 80
clinozoicite
crossed polarizers
40x

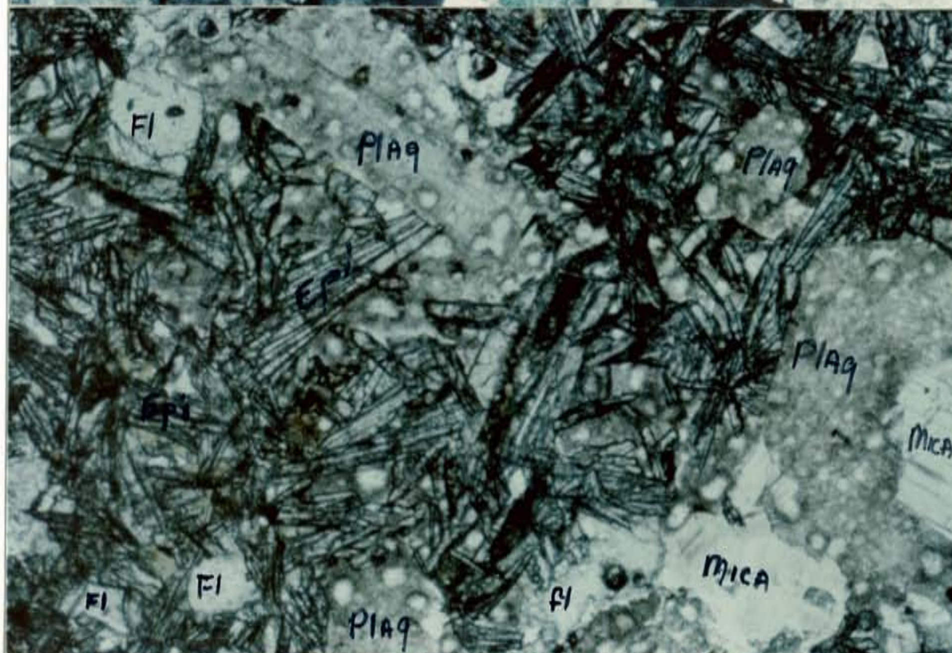


Figure 2.
Ladron pluton, LD 80
epidote, fluorite and
plagioclase
uncrossed polarizers
40x

Figure 3.
Ladron pluton, LD 80
epidote, fluorite and
plagioclase
crossed polarizers
40x

are often found as elongate prisms that, at times, form a radial pattern. Subhedral epidote is found partially included in plagioclase and microcline. Fluorite with octahedral cleavage traces is associated with the epidote. The only example of the epidote-fluorite mineral pair found during the present study is located in a canyon directly west of Canyon del Alamito and is sample LD 80 (figure 2a).

Zircon less than 1 mm in size is found included in biotite and usually surrounded with radioactive halos. Other grains of radioactive minerals, approximately 1 mm or less in length, are present but difficult to identify.

Crystallization sequence

The Ladron quartz monzonite shows evidence of two stages of crystallization (Table 14). The first stage is interpreted as magmatic crystallization and the second as alteration. This crystallization history is similar to the Capirote pluton. The minerals of the first stage have good crystal outlines. The plagioclase may be twinned or zoned and often is highly altered. The quartz usually occurs as single grains. The microcline is sometimes twinned and does not display sieve texture. Other minerals included in this stage are biotite, muscovite, and the accessory minerals shown in Table 14. The second stage is marked by the appearance of albitic plagioclase and microcline, both with lobate margins (plate 8, figure 2) and/or sieve texture. These crystals are sometimes poikilitic (perhaps poikiloblastic) and often replace the older first-stage minerals (plate 8, figure 1). Quartz of the second stage is often found as aggregates in veins that cross-cut

TABLE 14. SEQUENCE OF CRYSTALLIZATION IN THE LADRON PLUTON

	Magmatic (first stage)	Alteration (second stage)
Apatite Magnetite Zircon	________________ . . .?	
Plagioclase	________________________ . . . .?	________________?
Microcline	____________ . . . . . ________	. . . .?
Biotite	____________	.chlorite titaniferous mangnetite epidote sericite sphene (hematite & limonite)
Muscovite	____________	sericite alteration
Quartz	. . . . ______	__________________________________
Epidote		. . . . ______________
Fluorite		. . . . ________

other minerals. The alteration of biotite to chlorite, sphene, and magnetite may have occurred during the alteration stage. There was no specific time when all of the second-stage crystallization began; rather, it started in different areas of the pluton with the build-up of various residual liquids. The second-stage crystals are not uniformly spread throughout the pluton, but occur in local concentrations. The changing temperature, pressure, and amounts of late stage fluids may have been the controlling factors in the formation of these crystals. The second-stage minerals are interpreted as late features because they sometimes fill intersitial areas and replace earlier formed minerals. Based on crystal shape, included minerals, cross-cutting relationships, and replacement textures all mentioned earlier in the text, the crystallization sequence (Table 14) is proposed.

Bulk Composition

Major elements analyses if six samples of the Ladron quartz monzonite are shown graphically in figures 5-7 and given in Table 15. Samples were carefully chosen from various areas of the pluton to give a representative cross section of the pluton. The most important conclusion is that compositionally, the Ladron pluton is quite homogeneous. There is a narrow range in the oxides: TiO_2, Al_2O_3, Na_2O and K_2O. The narrow range in composition may reflect the Ladron pluton as being uniformly mixed and highly fractionated. MgO and CaO are the only oxides that fluctuate in concentrations. These fluctuations may be related to the secondary albite. Positive microscopic identification of all the secondary albite is dubious, and therefore the relationship

TABLE 15. MAJOR ELEMENT CONTENT OF THE LADRON QUARTZ MONZONITE

Oxide (weight percent)	Rock Samples							
	*LD1	LD7	LD77	LD79	LD84	*LD102	$\overline{X}$	STD
SiO_2	77.20	75.50	75.00	75.70	74.80	75.30	75.60	0.80
TiO_2	0.21	0.18	0.19	0.20	0.20	0.19	0.19	0.01
Al_2O_3	13.40	13.40	14.60	13.30	13.50	14.20	13.70	0.50
Fe_2O_3	0.04	1.01	0.43	1.21	1.19	0.12	0.67	0.49
MgO	0.29	0.37	0.15	0.43	0.51	0.50	0.37	0.13
CaO	0.29	1.15	1.38	1.02	0.98	1.23	1.01	0.35
Na_2O	3.84	3.45	3.39	3.26	3.61	3.66	3.53	0.19
K_2O	4.23	4.44	4.35	4.38	4.71	4.30	4.40	0.15

* = white facies
$\overline{X}$ = mean
STD = stand deviation (see Table 5)

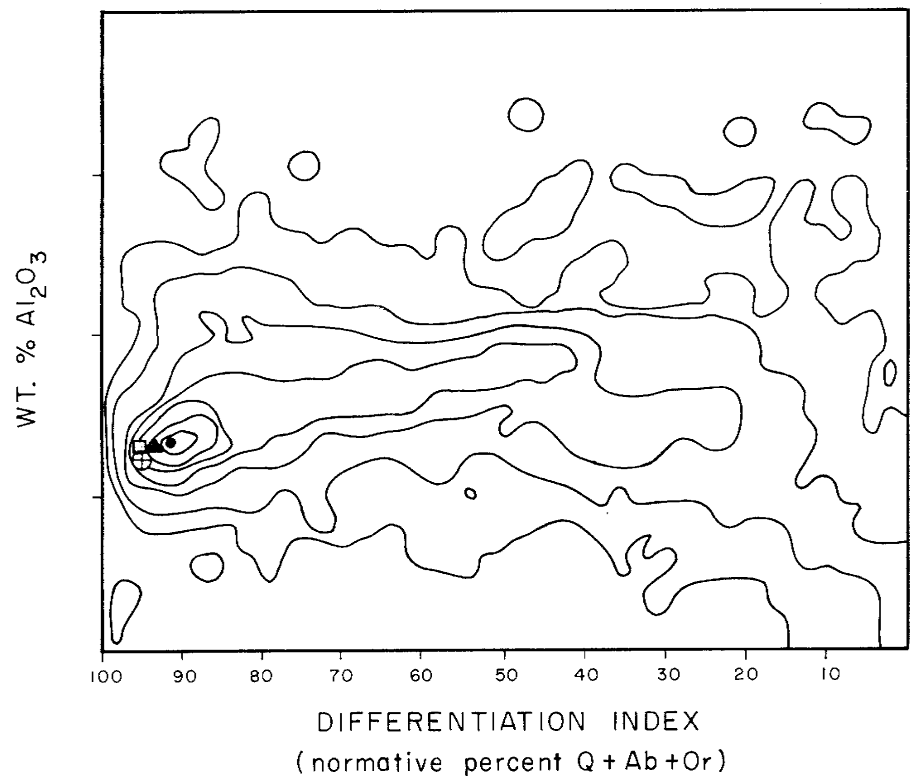
difficult to prove. Plots were attempted to establish a connection of MgO and CaO fluctuations with local concentrations of epidote, biotite, or magnetite. Results of these plots indicate no certain correlations, but high Ca concentrations in some samples seem to correspond with high epidote concentrations. The two major differences between the Ladron and Capirote intrusives are a narrower composition range and higher Al_2O_3 content in the former.

Mesonorms are plotted on phase equilibria triangles O-Ab-Or and An-Ab-Or on figures 5 and 6. Again, they show the Ladron quartz monzonite as a compositionally well defined pluton. Figure 5 shows a tight cluster of points very near the ternary minimum of Tuttle and Bowen (1958) with 500 bars P_{H_2O}. The An-Ab-Or mesonormative plot (Figure 6) shows LD 1 as lower in An content and somewhat enriched in Ab relative to the other rocks of the Ladron pluton. The thin section of sample LD 1 contains lobate sodic plagioclase replacing microcline. The compositional difference of the sample could be due to the grain size, the location within the white facies from which it was sampled, or a later geologic occurrence. A conclusion is simply not possible from a study of one sample. It is important to note, a residual fluid containing Or, Q and Ab had a dominant role in the formation of the white facies of the Labron pluton.

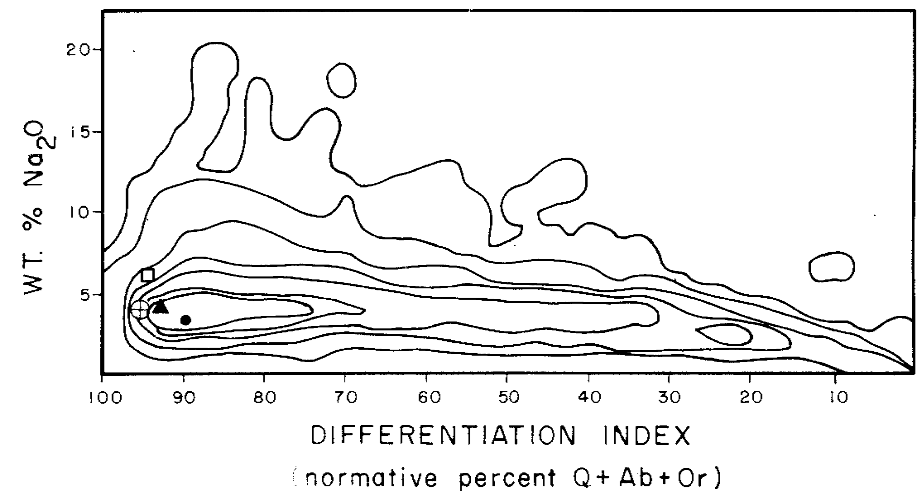
Chemical trends of the oxides $CaO-Na_2O-K_2O$ (figure 8) show the Ladron quartz monzonite enriched in CaO relative to most of the Capirote pluton. Again LD 1 is an exception; it is much higher in Na_2O and K_2O than the other samples from the Ladron pluton.

DISCUSSION AND CONCLUSIONS

The Ladron and Capirote plutons have many similarities. Modal diagrams (figures 3, 4, 8) indicate the bulk composition is in the quartz monzonite range. Normative data plots narrow the bulk composition of both plutons to a cluster of points near the ternary minimum of Tuttle and Bowen (1958) at 500b P_{H_2O} in the Q-Ab-Or system. Points representing the Ladron pluton are more closely packed on the ternary low temperature trough but, in general, the compositional range for both plutons is 35-45% Q, 35-50% Or and 50-65% Ab. Both the Ladron and Capirote quartz monzonites contain Al_2O_3 in molecular excess (Table 10-13) over the sum of K_2O, Na_2O and CaO. Thornton and Tuttle (1960) designed a differentiation index, using 5000 rock analyses from Washington's Tables as a numerical expression of the differentiation of magmas. The normative sum of Q, Or, and Ab, is used as the index of differentiation (or DI) which helps identify the distance a given magma has developed towards the "end point" of SiO_2- $NaAlSi_3O_8$-$KAlSi_3O_8$. The average differentiation index is very high for both plutons. The Ladron quartz monzonite is 91.5, the unaltered Capirote quartz monzonite is 93.2, the altered facies of the Capirote pluton is 93.3, and the granophyric facies is 95.7. Frequency distribution charts (figures 9 and 10) demonstrate approximate positions of average DI versus oxide distributions. The distribution charts show oxide contents of the Ladron and Capirote quartz monzonites plotted with contours for the 5000 analyses of Washington's Tables (Washington, 1917). Generally both quartz monzonites fall on or near maxima positions on the charts and



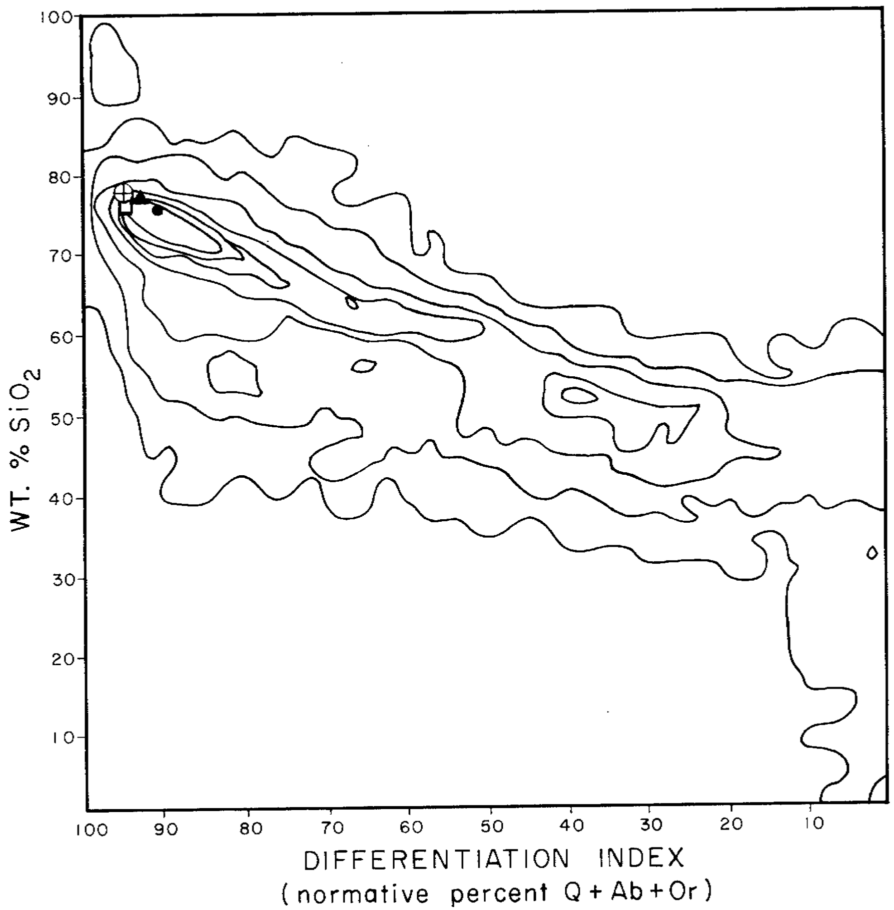
a. Differentiation Index (normative percent Q + Ab + Or) contoured diagram showing the distribution of the Al_2O_3 content of 5000 analyses of Washington's Tables as a function of differentiation index.
(Thornton and Tuttle 1960)



b. Differentiation index (normative percent Q + Ab + Or) contoured diagram showing the distribution of Na_2O content of 5000 analyses of Washington's Tables as a function of differentiation index.
(Thornton and Tuttle 1960)

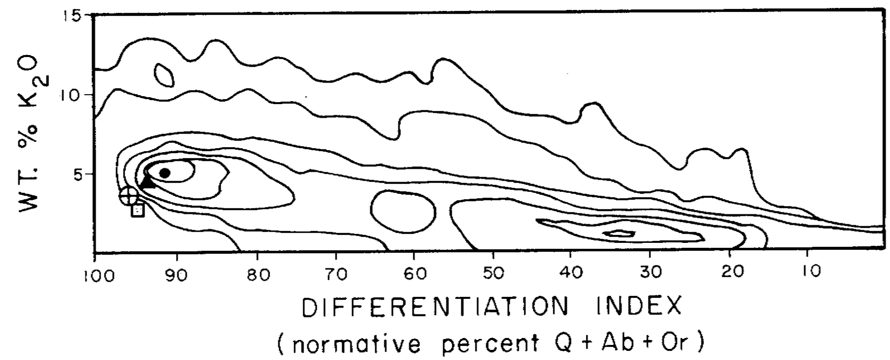
- ● Ladron Quartz Monzonite
- ▲ Capirote Quartz Monzonite, unaltered
- □ Capirote Quartz Monzonite, altered
- ⊕ Capirote Quartz Monzonite, granophyre

FIGURE 9



a. Contoured diagram showing the distribution of SiO_2 content of 5000 analyses of Washington's Tables as a function of differentiation index.
(Thornton and Tuttle 1960)

- ● Ladron Quartz Monzonite
- ▲ Capirote Quartz Monzonite, unaltered
- □ Capirote Quartz Monzonite, altered
- ⊕ Capirote Quartz Monzonite, granophyre



b. Differentiation Index (normative percent Q + Ab + Or contoured diagram showing the distribution of K_2O content of 5000 analyses of Washington's Tables as a function of differentiation index.
(Thornton and Tuttle 1960)

EXPERIMENTAL MELTS

water content in weight percent

0.2 1.2 2.5 20

magnetite	magnetite	magnetite	magnetite
plagioclase	plagioclase	plagioclase	plagioclase
alk.feldspar	alk.feldspar	alk.feldspar	biotite
quartz	quartz	biotite	alk.feldspar
biotite	biotite	quartz	quartz

c. Sequence of crystallization in a granite deduced from it's texture, compared with experimentally determined crystallization sequences at 2kb for different ranges of H_2O content. (Maaloe and Wyllie 1975)

FIGURE 10

are over-saturated in silica (figure 12a). The two plutons also have some petrographic similarities; both are subsolvus "granites" according to Tuttle and Bowen's (1958) classification. They are considered subsolvus because plagioclase is present as discrete grains; biotite, muscovite, and low temperature feldspars are all present; and the plutons are missing large zoned pegmatites. The point at which biotite began crystallizing in both plutons suggests they had variable H_2O content, figure 10c, (from 2.5-20 percent, Maaloe and Wyllie 1975). Both plutons have massive looking feldspars with sieve texture and lobate margins (plate 3, figure 1 and plate 8, figure 2), poor development of plagioclase twins, and biotite as the dominant mafic mineral. Although the Ladron intrusion is clearly younger than the Capirote pluton, the above petrologic similarities suggest similar crystallization histories.

The Capirote intrusive was emplaced at shallow depths (epizone of Buddington's classification, 1959). A number of relationships point toward this conclusion. The composition of the pluton is diverse from the inclusions of country rocks, especially in border and roof zones. Roof pendants are common and the volcanic rocks that form the roof pendants in some areas may be genetically related to the pluton. Aplite dikes are not common, but evidence for granitization of the quartzite sequence is widespread, especially in the area around Cerro Colorado as previously described. Granophyre, which is characteristic of shallow emplacement, occurs locally as a roof facies, and the contact zones of the Capirote pluton with older volcanic rocks are sharp.

Emplacement of the Capirote pluton was forceful, characterized by magma stoping. The large number of various sized angular inclusions of country rock in the pluton may reflect processes of magma rise and relaxation, pulling awary blocks and fracturing the brittle country rock.

The Capirote pluton is quite heterogeneous in composition. Two examples of this diversity can be logically explained using this study: the reason for the granophyric and coarse-grained facies, and the reason for the albitized portions of the pluton.

The granophyric and coarse grained facies most likely have similar origins. The areas in which both facies are found (near Ladron Peak) represent portions of the top of the pluton, perhaps cupolas. Experimental sudies of Wyllie and Tuttle (1961) suggest albite crystallized from glass in the presence of HF solutions is several times larger than that crystallized in the presence of H_2O alone. Fluorite is found in the LD 90 series as a primary mineral (plate 2, figure 2). The LD 90 series includes the coarse-grained facies with some intersititial granophyric intergrowth (plate 2, figure 1). The coarse-grained facies, then, may have crystallized under the influence of volatiles, including HF, that concentrated at the top of the Capirote pluton. The granophyre probably had the same origin. Jahns et al. (1969) experimentally produced normative albite and quartz by aqueous vapor transport; conceivably granophyre could be produced in this way.

The albitization of the Capirote pluton may have occurred during the intrusion of the Ladron pluton. The Ladron intrusion heated portions of the Capirote pluton where it was then albitized. Clearly (plate 4, figures 1 & 2) replacement was the mechanism of enrichment. This conclusion fits Orville's (1963) model (see page 50 of this report) and the field evidence. The amount of albitization is directly related to the closeness to the contact of the Ladron pluton. The source of the Na, whether from the Ladron intrusion or remobilized from the Capirote pluton, is beyond the scope of the present study.

Several noteworthy characteristics suggest emplacement of the Ladron pluton at intermediate depths (mesozone) of Buddington's classisfication (1959). The country rock is only slightly altered. The pluton was not emplaced by reconstitution of replacement of the country rock. The minor evidence for forceful uplift of country rock can be seen on the ridge just east of Monte Negro. The Precambrian volcanics of the area bear no direct genetic relationship to this pluton. The Ladron intrusive has a complex discordant relationship to the older Precambrian rocks and is itself composite, made up of two units, the white facies being slightly more alkalic and siliceous. The Ladron pluton may have been a more passive intrusion than the Capirote event. The Ladron intrusion caused little change in the older rocks and yet it had enough volatile pressure to emplace late-stage aplite and quartz dikes, discordant to the country rocks.

The origin of both plutons is a topic that cannot be defined from this study. Most workers (Carmichael, 1963; Piwinskii, 1968; Kleeman, 1965; Barker, 1975; Whitney, 1975; Brown and Fyfe, 1970; and Tuttle and Bowen, 1958) have suggested about 700° C as the emplacement temperature for similar plutons. If the quartz monzonites were H_2O saturated and emplaced at T=700° C, the experimental data of Tuttle and Bowen (1968) indicate a maximum depth of emplacement of 7 km or 2 kb pressure. The origin of the granitic material, whether it be fractional crystallization or partial fusion of crustal material or even a mantle derivation, is not within the scope of this study.

An important conclusion can be made however: After the Capirote intrusion the site of magma generation in the crust (or upper mantle) would be so depleted with respect to granitic material that it could not be used to derive a second granitic magma of the same general composition. This is only possible if there was movement of granitic material from another source to produce the Ladron magma or if the source area had been replenished.

REFERENCES CITED

Armstrong, A. K., 1959, The Mississippian of west central New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 5, 34 p.

Bailey,E. H. and Stevens, R. E., 1960, Selective staining of K-feldspar and plagioclase on rock slabs and thin sections: Am. Mineralogist, v. 45, p. 1020-1025.

Barker, D. S., 1970, Compositions of granophyre, myrmekite, and graphic granite: Geol. Soc. America Bull., v. 81, p. 3339-3350.

Barth, T., 1959, Principles of classification and norm calculations of metamorphic rocks: Jour. Geology, v. 67, p. 135-152.

Bateman, P. C. et al., 1963, The Sierra Nevada Batholith, a synthesis of recent work across the central part: U.S. Geol. Survey Prof. Paper 414-D, p. D1-D46.

Black, B. A., 1964, The Geology of the Northern and Eastern Parts of the Ladron Mountains, Socorro County: New Mexico [Masters thesis]: Alburquerque, Univ. of New Mexico, 117 p.

Brown, G. C., and Fyfe, W. S., 1970, The production of granitic melts during ultrametamorphism: Contr. Mineralogy and Petrology, v. 28, p. 310-318.

Bruning, J. E., 1973, Origin of the Popatosa Formation [Ph.D. Dissert.] Socorro, New Mexico Institute of Mining and Technology.

Buddington, A. F., 1959 Granite emplacement with special reference to North America: Geol. Soc. America Bull., v. 70, p. 671-747.

Carmichael, I.S.E., 1963, The crystallization of feldspar in volcanic acid liquids: Geol. Soc. London Quart. Jour., v. 119, p. 85-131.

Chayes, F., 1956, Petrographic modal analysis: New York, John Wiley and Sons, 113 p.

Condie, K. C. and Lo, H. H., 1971, Trace element geochemistry of the Louis Lake Batholith of early Precambrian age: Geochim. et Cosmochim. Acta, v. 35, p.1099-1120.

Condie, K. C., 1976, Precambrian rocks of the Ladron Mountains, Socorro County, New Mexico: New Mexico Bur. Mines and Mineral Resources, Geologic map 38.

Condie K. C. and Budding, A. J., 1977, in preparation.

Cross, W. et al., 1902, A quantitative chemico-mineralogical classification and nomenclature of igneous rocks: Jour. Geology, v. 10, p. 555-690.

Darton, N. H., 1928, Geologic map of New Mexico: U.S. Geol. Survey, scale 1:500,000.

Denny, C. S., 1940, Tertiary geology of the San Acacia area, New Mexico: Jour. Geology, v. 48, p.43-106.

Flanagan, F. J., 1973, 1972 values for international geochemical reference samples: Geochim. et Cosmochim. Acta, v. 37, p. 1189-1200.

Haederle, W. F., 1966, Structure and metamorphism in the southern Sierra Ladrons, Socorro County, New Mexico [Master's thesis]: Socorro, New Mexico Institute of Mining and Technology, 56 p.

Jahns, R. H. et al., 1969, Origin of granophyre in dikes and sills of tholeiitic diabase (abs.): Am. Geophys. Union Trans., v. 50, p. 337.

Kelley, V. C. and Wood, Jr., G. H., 1946, Lucero uplift, Valencia, Socorro and Bernalillo counties, New Mexico: U.S. Geol. Survey, Oil and Gas Inv. prelim. map 47.

Kleeman, A. W., 1965, The origin of granite magmas: Jour. Geol. Soc. Australia, v. 12, p. 35-52.

Leake, B. E., et al., 1969, The chemical analysis of rock powders by automatic X-ray fluorescence: Chem. Geology, v. 5, p. 7-86.

Maaloe, S. and Wyllie, P. J., 1975, Water content of a granitic magma deduced from the sequence of crystallization determined experimentally with water-undersaturated conditions: Contr. Mineralogy and Petrology, v. 52, p. 175-191.

Noble, E. A., 1950, Geology of the southern Ladron Mountains, Socorro County, New Mexico [Master's thesis]: Albuquerque, Univ. New Mexico, 81 p.

Norrish, K. and Hutton, J. T., 1969, An accurate X-ray spectographic method for the analysis of a wide range of geological samples: Geochim. et Cosmochim. Acta, v. 33, p. 431-453.

Orville, P. M., 1963, Alkali ion exchange between vapor and feldspar phases: Am. Jour. Sci., v. 261, p. 201-237.

Piwinskii, A. J., 1968, Studies of batholighic feldspars: Sierra Nevada, California: Contr. Mineralogy and Petrology, v. 17, p. 204-223.

Schroeder, G. L., and Winchester, J. W.,]962, Determination of sodium in silicate minerals and rocks by neutron activation analysis: Analytical Chem., v. 34, p. 96-99.

Smith, J. R., and Yoder, H. S., 1956, Variation in X-ray powder diffraction patterns of plagioclase feldspars: Am. Mineralogist, v. 40, p. 632-647.

Thorton, C., and Tuttle, O. F., 1960, Chemistry of igneous rocks I, differentiation index: Am. Jour. Sci., v. 258, p. 664-684.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geol. Soc. America Mem., 74, 142 p.

Van der Plas, C. and Tobi, A. C., 1965, A chart for judging the reliability of point counting results: Am. Jour. Sci., v. 263, p. 87-90.

Volborth, A., 1963, Total instrumental analysis of rocks part A: Nevada Bur. Mines, Rept. 6, 72 p.

Washington, H. S., 1917, Chemical analyses of igneous rocks published from 1884 to 1913: U.S. Geol. Survey Prof. Paper 99.

Whitney, J. A., 1975, The effects of pressure, temperature, and X_{H_2O} on phase assemblage in four synthetic rock compositions: Jour. Geology, v. 83, p. 1-31.

Wyllie, P. J. and Tuttle, O. F., 1961, Experimental investigation of silicate systems containing two volatile components II. The effect of NH_3 and HF in addition to H_2O on the melting temperature of albite and granite: Am. Jour. Sci., v. 259, p. 128-143.

This thesis is accepted on behalf of the faculty of the

Institute by the following committee:

Date April 28, 1978