

THE PETROLOGIC STUDY OF A
MICROSYENITE INTRUSION IN BREWSTER COUNTY, TEXAS

A Thesis
Presented to
the Faculty of the Department of Geology
The University of Houston

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

by
Thomas DeWitt Altman

May, 1970

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ABSTRACT

The Mountain 4320 microsyenite intrusion consists of a large, elliptical-shaped, hypabyssal stock or laccolith (the main mass), two elongate sills (the north and south prongs) and numerous small dikes. These masses are intrusive into sediments of Upper Cretaceous age. The intrusive rocks are a holocrystalline, porphyritic mixture of medium-grained, subhedral alkali feldspar phenocrysts and rare pyroxene phenocrysts in a fine-grained allotriomorphic granular groundmass. The groundmass is predominantly subhedral, alkali feldspar laths with felted to fluidal textures. The alkali feldspar phenocryst and felsic groundmass minerals account for more than 83 per cent of the bulk of these rocks.

2V's of the alkali feldspars range from 18° to 57° . Phenocryst samples from the center of the main mass appear to have larger 2V values than samples at its periphery. The 2V data indicate a low sanidine structural state for the samples analyzed.

Composition analyses (estimation of mole % Or by x-ray diffraction) show the phenocrysts of these rocks to vary from 28 to 41 mole per cent Or. Based on these analyses, the rocks of the main mass are divisible into chilled zone or periphery samples (phenocrysts > 36 mole % Or) and interior or core samples (phenocrysts < 36 mole % Or). The south prong, north prong and dikes have average phenocryst compositions of 39, 41, and 40 mole per cent Or respectively. Groundmass compositions range from 40 to 46 mole per cent Or.

Most of the alkali feldspars are cryptoperthitic mixtures of K and Na phases which have anomalous cell dimensions. The K phase of these mixtures has low sanidine structural states. Samples from the main mass periphery, the prongs, and the dikes, however, contain both the cryptoperthitic mixtures and a homogeneous phase or a homogeneous phase alone. These samples have low to high sanidine structural state equivalents and normal cell dimensions. Further study is required to determine if these latter samples are sanidines or anorthoclases.

The crystallization history of these rocks (based primarily on the alkali feldspar relations) can be accurately traced in the system Ab-Or-An-Q. The crystallization sequence derived for these rocks agrees well with previous laboratory and natural rock studies in this system.

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INTRODUCTION

The soda microsyenite selected for this study occurs in small intrusions emplaced in Upper Cretaceous sedimentary rocks in an area of approximately two square miles. The igneous masses present are (1) a large elliptical-shaped hypabyssal mass (referred to as the "main mass" or "Mountain 4320"); (2) two planar igneous masses (referred to as the "north" or "south" prong, or collectively as the "prongs"); and (3) numerous small dikes. These collective masses were named the Mountain 4320 area by J. T. Lonsdale in 1940.

Location and Accessibility

The Mountain 4320 area is a small portion of the Chiricahua Ranch which is located in southwestern Brewster County in the Big Bend Region of Trans-Pecos Texas. The area is immediately adjacent to Highway 118, 9.5 miles north of Study Butte and immediately south of the Adobe Walls Mountain igneous complex (Figure 1).

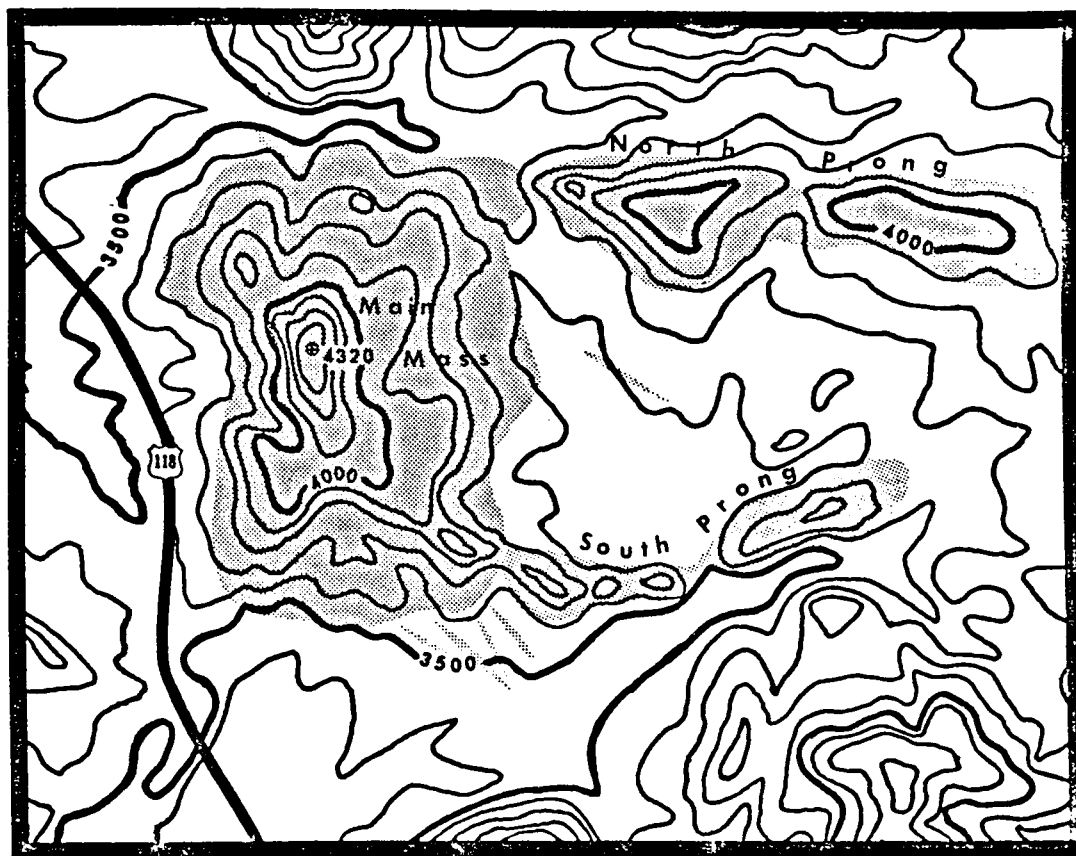
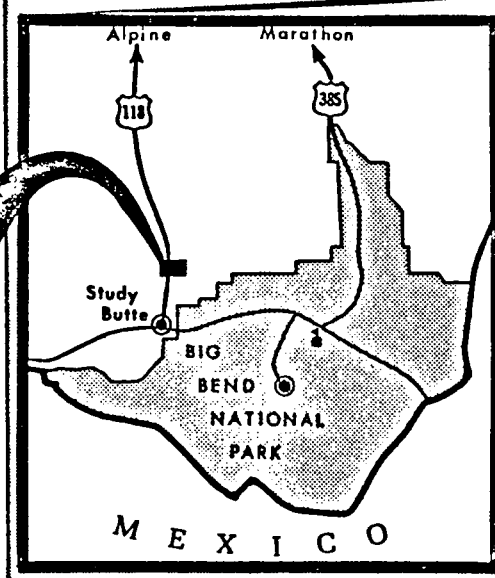
The area is accessible from Big Bend National Park (25 miles to the south) and Alpine (70 miles to the north) via State Highway 118, an all-weather, paved road. Numerous ranch trails allow easy access, by sturdy vehicles, to most of the low relief portions of the area.

Purpose of Thesis

The objectives of this thesis are:

(1) to investigate the petrology of the area with emphasis on the details of feldspar variation;

INDEX MAP



0 FEET 5000

Approximate Igneous Outcrop

Figure 1. Index Map of the Mountain 4320 Area.

(2) to test published feldspar investigation methods and techniques on natural, hypabyssal samples; and

(3) to learn new details of the crystallization history of feldspars and obtain possible trends of alkaline magmatic evolution.

Numerous possible corollary studies came to light during the development of the objectives above. These are listed in annotated form in Appendix 9. This writer intends to pursue most of these interesting studies in the near future.

REGIONAL SETTING

The southern portion of the Big Bend region is arid and mountainous, and appears to have more geographic affinity to Mexico than to the rest of Texas. The rainfall, which averages 15 inches a year, ideally suits the Chihuahuan fauna and flora which lend the area its distinctive aura.

Differential erosion has produced pronounced relief; the highest point, 7835 feet, is on Emory Peak in the Chisos Mountains; the lowest point, the flood plain of the Rio Grande, has an elevation of 2,000 feet. The sedimentary rocks exposed in the area range in age from Cretaceous to Recent. Tertiary igneous activity is represented by several hundred dikes, sills, plugs, laccoliths, and irregular plutons which have intruded the sedimentary rocks. Removal of the sedimentary rocks has left these numerous monolithic masses of igneous rocks arranged without apparent system over the landscape. This lack of systematic arrangement has produced intermontane areas which are irregular in size and shape.

Most of the prominent structural features of the region were generated during the Laramide Orogeny (Late Cretaceous or Early Tertiary). The dominant feature is a northwesterly-trending graben, approximately 40 miles wide, called the Sunken Block (Udden, 1907). This graben extends northward beyond the Rio Grande and is bounded on the east and northeast by the Sierra del Carmen range and on the southwest by the Solitario uplift and the Terlingua fault. The Sunken Block is a topographic depression which is structurally 4,000 - 6,000 feet below the Lower Cretaceous highland boundaries.

Mountain 4320 is one of the numerous Late Cretaceous to Tertiary igneous masses within the Sunken Block, and it lies near the northern termination of the depression. All of these igneous masses belong to the Trans-Pecos Texas Alkaline Province, in which the rocks range from basalts through trachyandesites and rhyolites to riebeckite-rhyolites.

FIELD RELATIONS

Field Work

Specimen collection and mapping were completed in two trips to the area, in 1965 and in 1968. The igneous rocks are megascopically homogeneous so that no field-determined differentiation or subdivision was possible. Thus most effort in the field was exerted in making accurate sample locations and securing fresh, in place samples. Due to the intense surface weathering, most samples were quarried using a ten-pound sledge hammer. In some instances, especially on the prongs, fresh samples were unobtainable. Sample locations were determined with a Brunton compass by the intersection method, and plotted on a 1" = 500' topographic base map. Figure 2 shows the spatial distribution of the 245 samples collected in this study as well as the collection of Dr. M. F. Carman (labeled MC).

General Form of the Intrusion

Main Mass. The main mass (Mountain 4320) is roughly elliptical-shaped with the major axis north-south (see Figure 2) parallel to Highway 118. The maximum relief of the mass above the sedimentary rock contact is 850' and the average is 600'. Most slopes are gentle, 5° to 20°, but some of the higher east and west facing slopes reach 50° and are difficult to traverse. All slopes of less than 5° are covered with boulder rubble, and in place samples are difficult to obtain. Slope detritus ranges from silt-sized to boulders larger than 8 meters in diameter. Most slope rubble is in the form of small subequant fragments 10 cm. to 40 cm. in diameter. Intense surface weathering is always present in the outer 2 to 15 cm. of rock, and in some instances boulders up to 50 cm. in diameter show alterations to the core. Many of the opened boulders have concentric bands of differential

Figure 2



weathering from intense at the surface to slight at the core. Rarely the boulders show spheroidal exfoliation. Fresh-rock colors⁽¹⁾ range from gray (N5) to bluegray (5B7/1) and green-gray (5GY6/1); weathered rock colors range from gray-brown (5YR G/1) to brownish-gray (5YR4/1). Laboratory study has shown the brown tones to be from weathering of the mafic minerals. There is no apparent system to the slight changes in chroma and hue noted in the fresh rocks of the mass. All samples from this main mass have clear and unweathered feldspar phenocrysts which are easily visible in hand specimen. The only petrographically significant details visible in the field were the contact rocks which display distinctive, blotchy or crudely laminar mixtures of gray and green-gray groundmass material as well as occasional vesicularity.

Attitudes of sedimentary rock near the contact zone were generally obscured by rubble; those that were visible are recorded on Figure 2. Based on (1) the extreme variability of sedimentary rock attitudes over relatively short intervals at the contacts, (2) rock textures (finer grained near the contacts), and (3) the outcrop form (elliptical shape), this mass is probably a discordant stock or a laccolith with locally discordant contacts. J. T. Lonsdale (1940) felt the mass represented the basal portion of a laccolith. Only a coring program, blasting, or possibly a gravity or magnetic survey will prove either supposition. Small-scale concordant and discordant portions of the mass could be present under either supposition.

Prongs. To the northeast and southeast of the main mass, two apparently planar, sill-like masses (the north and south prongs) project to the east. Both are separated from the main mass by narrow gaps. Maximum

(1)

As determined from the Geological Society of America Rock Color Chart

relief of these rocks is 300' above the sedimentary rock contact. They form gentle, rubble-covered slopes that are easily traversed. Both masses are more weathered than the rocks of the main mass. The western portion of the south prong is most like the main mass in outcrop appearance, with brownish-gray and yellowish-gray (5Y 7/2) colors. The eastern portion of the south prong is characterized by yellowish-gray very pale-orange (10YR 8/2) colors. The rocks of the north prong are completely weathered in the outer meter or so, and no fresh samples were obtained.

The attitudes of sedimentary rocks near the contacts of the prongs are more concordant than against the main mass. Thus, in this instance, this writer agrees with J. T. Lonsdale (1940) in terming these masses sills. Figure 3 shows a schematic cross section view of the prong intrusives and their relationships to the containing sedimentary rocks as deduced from field mapping. The relationship among the north prong, the south prong and the main mass is unknown.

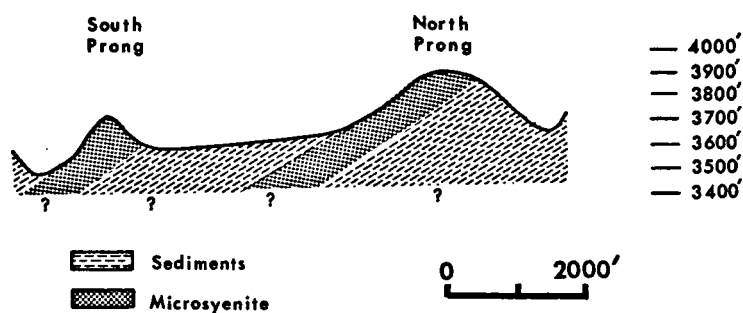


Figure 3. A schematic North-South cross section through the prongs as deduced from field relationships.

Completely weathered small outlyers (up to 400' across) of the south prong continue eastward for more than a mile toward the Christmas Mountains.

Dikes. Numerous small dikes of diabase and microsyenite were noted in the sedimentary rocks surrounding the main mass and between the prongs. These dikes range from 2' to 15' across and 60' to 425' long. Most have a northwest-southeast trend and protrude above the sedimentary rocks as ridges 2' to 8' high due to their superior resistance to erosion. Some of the microsyenite dikes may well be satellites of the main mass, but lack of connection and extensive alteration of these thin bodies make any correlation difficult, and the exact age relationships between the dikes and the main mass are uncertain. No detailed study of the dike rocks was performed, although several were analyzed for feldspar phenocryst composition as reported in Table 4.

Bordering Masses. Immediately to the north of the main mass (separated 100' at the closest point) is the southern-most portion of the Adobe Walls Mountain complex. This portion of the complex is a sodic riebeckite microgranite. To the east of this mass and to the north of the north prong, sediments are exposed but their domal attitude indicates another (or possibly the same) intrusion is present in the shallow subsurface.

Four miles to the east are the very extensive Christmas Mountains. They contain porphyritic microgranite, sodic microgranite, microsyenite, diabase, and gabbro, all intruding Upper Cretaceous rocks. As mentioned earlier, outlyers of the prong rocks extend discontinuously eastward toward these mountains. Sedimentary rock attitudes and terminations imply the existence of a large fault to the east of the prongs (500' to 1,000' east of the edge of Figure 2) with a north-south trend.

South of the main mass 1 mile is a very large unnamed mass of sodic riebeckite microgranite. Portions of this same mass continue eastward along the south prong and in places they are separated by narrow (200') gaps.

600 feet southwest and west of the main mass is an alkali micro-syenite sill with a good road cut exposure along Highway 118. This mass may have an origin similar to the main mass of this study. It is being studied by Dr. J. C. Butler.

Sedimentary Rocks

Because of the emphasis placed on igneous petrology in this study, no extensive examination or mapping of the intruded Upper Cretaceous rocks were performed. Specimens were collected, attitudes measured and thin sections were made for lithologic descriptions and examination for possible contact metamorphism and/or metasomatic effects. The stratigraphic names used are those recommended by Maxwell, Lonsdale, Hazzard, and Wilson (1967).

Boquillas Formation. These are dark gray (N4) to black, 10 cm.- to 60 cm.-thick flags of medium crystalline fetid limestone separated by thinner layers of limy shale, all of which weather to grayish-yellow (5Y8/4) or yellowish-gray (5Y8/1). Individual beds are often faintly laminated, and may contain up to 10 per cent fine sand to fine silt-sized detrital quartz. Small prism-shaped fragments of broken *Inoceramus* shells are common, but no whole specimen was found. These rocks are exposed mostly in the valley between the north and south prongs.

Pen Formation. This consists of medium gray (N6) (pale yellowish-brown, 10YR6/2 on weathered surfaces) soft, structureless clay, and rare thin beds of argillaceous limestone. Upon exposure the clay erodes rapidly to produce low rounded hills. It is found commonly in the valley south of Mountain 4320. No fossils were found, nor were any trustworthy attitude measurements possible.

Aguja Formation. This is the youngest part of the sedimentary section exposed in the area. It consists of light gray (N7) pale brown (5YR5/2), or yellowish-gray (5Y8/1) sandstones and clays with thin limestone beds. The sandstones are massive, clay bonded (or rarely calcareous cemented), immature, medium sand-sized, quartz arenites which contain small amounts of plagioclase, chert, biotite, kaolinized material (potassium feldspars) and fossil fragments. The interlayered clays resemble the Pen Formation but are more silty and arenaceous. Coaly fragments are common. The thin limestone beds contain many fossils such as pelecypods (*Exogyra* sp.), gastropods, and cephalopods. Aguja outcrops are common south of Mountain 4320.

Contact Metamorphism

Sedimentary rocks adjoining the intrusive bodies were often bleached and indurated by the heat of intrusion. This pronounced decrease in intensity of color is most likely due to carbonaceous components being volatilized and driven off. No apparent addition of new substances from the igneous rocks occurred. Yates and Thompson (1959) noted calcite and clay mineral recrystallization near similar igneous masses to the south. They theorized that connate and meteoric waters dissolved and redeposited some minerals due to the heat of the intrusion. cursory study of thin sections from the sedimentary rocks adjacent to the main mass showed virtually no effects other than the forementioned volatilization of carbonaceous material.

PREVIOUS INVESTIGATIONS

Mountain 4320 Area

J. T. Lonsdale (1940) briefly described the petrology of Mountain 4320 in a careful survey of the igneous rocks of this region. He felt the mass represented the basal portion of a laccolith which had weathered to its present configuration. He described the rock as an aegirine-augite soda rhyolite. Dr. M. F. Carman has compiled a great deal of unpublished petrographic information on the area. Much of this data was made available to the writer during this work.

Alkali Feldspar Studies

The volume of literature presently available on feldspars in general, and alkali feldspars in particular, precludes any simple and concise historical review. A survey of the published work on alkali feldspars would in fact be an undertaking of appreciable magnitude.⁽¹⁾ Two recent works which cover the historical development of these studies and their resulting implications are by Deer, Howie, and Zussman (1963) and Barth (1969); both can be recommended to the interested reader. Developments in these studies have, in recent years, been so numerous as to outdate many works before they were published. For example, the Barth work referred to above was incomplete on the date of issue due to the studies of Stewart and Wright published contemporaneously.

(1)

During the final draft stage of this work, "A Bibliography of the Feldspars" edited by D. R. Walbaum and published by University Microfilms, Ann Arbor, Michigan, was released. This 144-page bibliographical listing has 2,000 works, of which one-half to two-thirds refer to alkali feldspars.

The theoretical bases for this study are primarily from the works of Wright and Stewart (1968), Wright (1968), Orville (1967 and 1963), Bowen and Tuttle (1950), Tuttle and Bowen (1958), Carmichael (1965, 1963, 1962, and 1960), MacKenzie (1957, 1956, and 1952), and MacKenzie and Smith (1962, 1959, 1956, and 1955).

Most of the applied studies on natural alkali feldspar assemblages are based on either plutonic or volcanic rocks; the study of hypabyssal assemblages (such as these Mountain 4320 rocks) lags far behind. No published research was noted which parallels this study in both methods and rock type.

METHODS OF STUDY

Laboratory Methods

The routine sample preparation procedures are presented in graphic form in Figure 4. The various specific analyses and techniques are discussed in the Appendix.

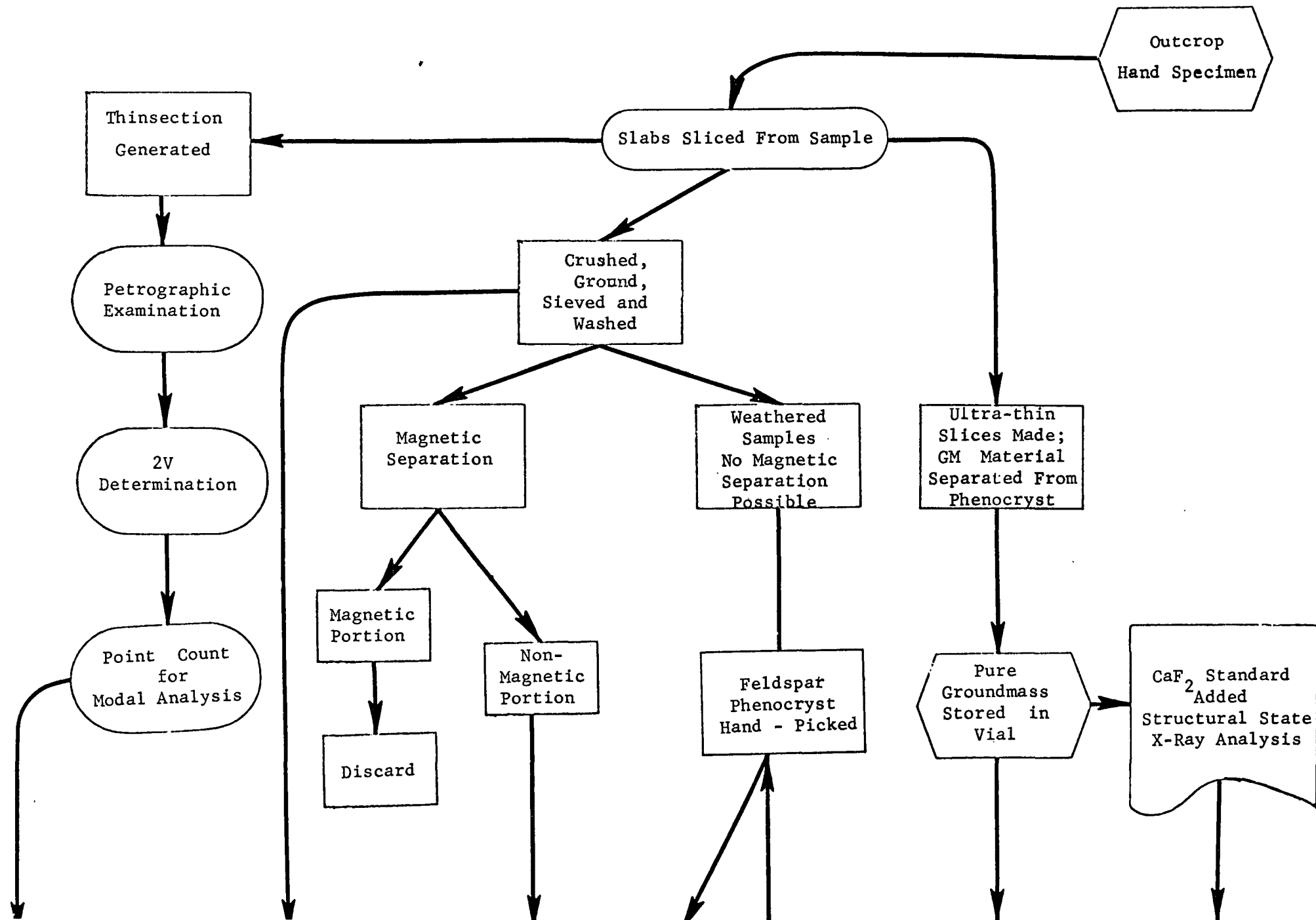
Optical Determinations

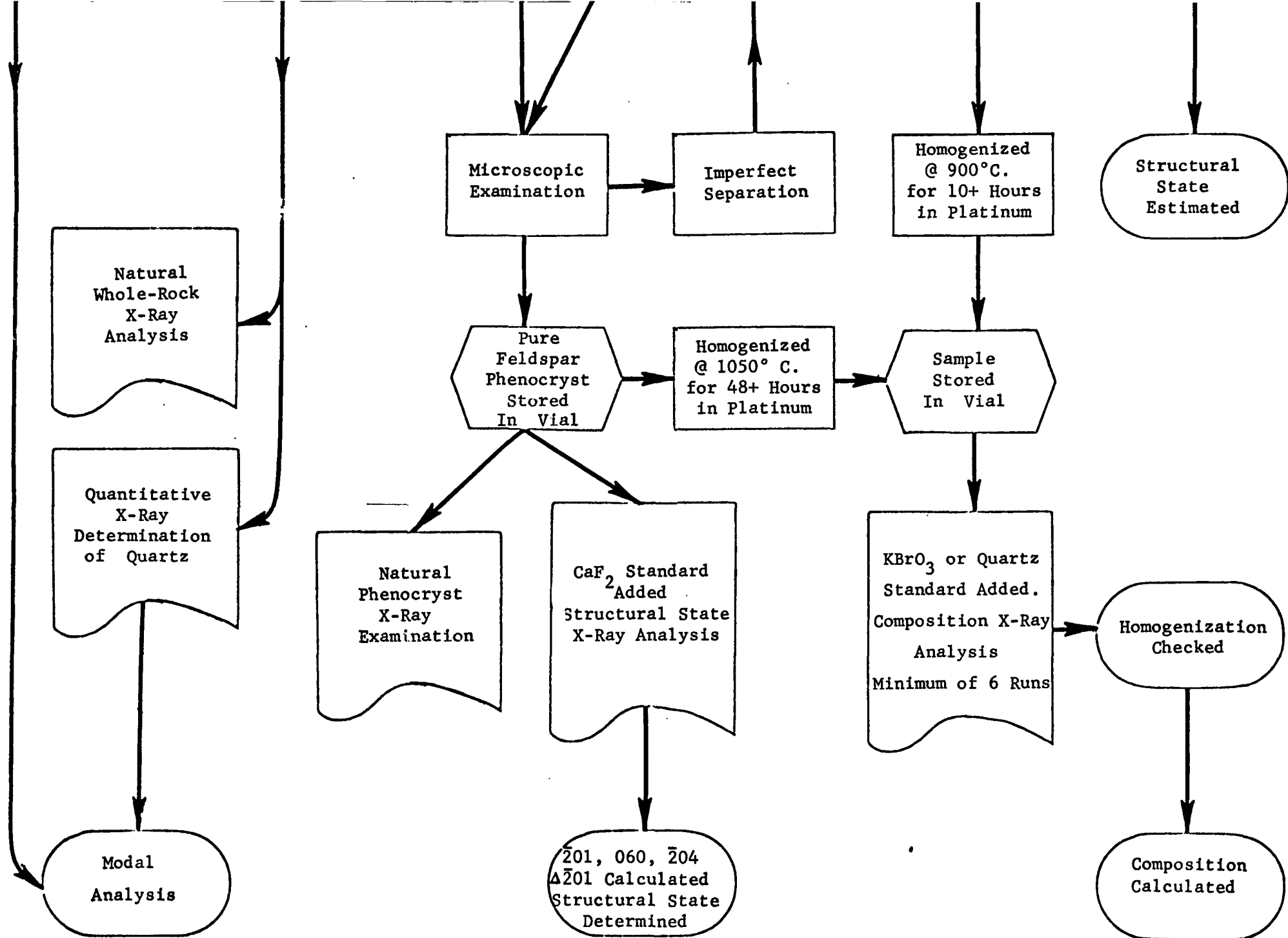
All optical work was performed with Zeiss petrographic microscopes on standard thin sections using classical determinative techniques.

Determination of 2V's were made with a Zeiss 4 axis universal stage in white light. Both conoscopic and orthoscopic methods were used. Readings on the outer E-W axis of the universal stage were made three times in each 45° position and the mean was taken as suggested by Fairbairn and Podolsky (1951). Optic axis 2V determinations as presented in Table 2 are reproducible to $\pm 1.5^\circ$.

Point count procedures for the modal analyses were unorthodox because of the inability of this writer to distinguish unequivocally very fine-grained quartz and feldspar in these rocks. Numerous techniques were attempted to allow differentiation of these species. The usual procedure, staining alkali feldspars with sodium-cobaltinitrite, was not selective enough for these rocks. Chayes and Zies (1962) noted similar difficulties on volcanic and hypabyssal alkali feldspars; they attributed the problem to an insufficiency of potassium on the surface of the grains. Attempts at differentiation based on selective etching by hydrofluoric acid, phase contrast determinations, and other types of stains were unsuccessful. Thus, the felsic groundmass material < 0.3 mm. in grain size was counted as such, and not as quartz or feldspar. The amount of quartz present was calculated

Figure 4. Routine Sample Preparation Procedures





by x-ray diffraction procedures and incorporated with the optically-determined point count analysis. Complete modal analyses are tabulated in Table 1; details of the quantitative x-ray diffraction determination of quartz are presented in Appendix 6, and details of the modal analyses in Appendix 8.

X-Ray Diffraction Determinations

All x-ray diffraction determinations were performed with Phillips high-angle x-ray diffraction units using nickel-filtered copper radiation or single crystal monochromator ($\text{Cu}_{K\alpha} = 1.5418 \text{ \AA}$). Each sample to be analyzed was crushed and the feldspar phenocrysts were separated (Appendix 1). A portion of the phenocrysts was homogenized (Appendix 2), combined with KBrO_3 standard and analyzed for KAlSi_3O_8 content (Appendix 3). Another portion of the natural phenocrysts was combined with CaF_2 standard and analyzed for structural state (Appendix 4). The feldspar phenocryst composition findings are presented in Tables 4 and 5 and on Figure 14. The structural state analyses are tabulated in Tables 9 and 10. A limited number of groundmass samples were treated similarly and are reported with the phenocryst results.

In the initial stages of this study, many natural whole rock x-ray diffraction analyses were performed to check homogenization techniques and gain insight into the variability of the minerals.

NOMENCLATURE

Igneous Rock Classification

The rocks of this mass were found to be a soda microsyenite based on the classification scheme of A. L. Streckeisen (1967). In this classification, a soda microsyenite contains 0 to 20 per cent quartz; 0 to 20 per cent feldspathoids; soda pyroxenes or amphiboles; and has a feldspar ratio ($=\text{plagioclase}/\text{total feldspar}$) of from 0 to 10. This is the most recent, and a well-received, classification system, and thus was chosen for use throughout this work. The "micro-" adjective-prefix is in accord with the French usage for designating hypabyssal rocks.

Alkali Feldspar Terminology

The terminology used for alkali feldspar polymorphs is that recommended by Wright and Stewart (1969). This particular scheme was chosen because it incorporates both chemical and structural variations, and it reflects the most recent and comprehensive alkali feldspar data available. A thorough review of their terminology can be found in Appendix 5.

PETROGRAPHY

The rocks of the Mountain 4320 intrusion are a holocrystalline, porphyritic mixture of medium-grained, subhedral alkali feldspar phenocrysts and rare pyroxene phenocrysts in a fine-grained hypautomorphic granular groundmass. The feldspar phenocrysts, which range from anhedral to euhedral, commonly occur as glomerocrysts of up to twenty individuals (see Figure 5). The groundmass is predominantly subhedral alkali feldspar laths with minor amounts of granular pyroxene and very fine-grained intergranular quartz, alkali feldspar, zircon, pyroxene, opaque iron oxides and riebeckite (see Figure 6). Textures range from felted to distinctly fluidal.

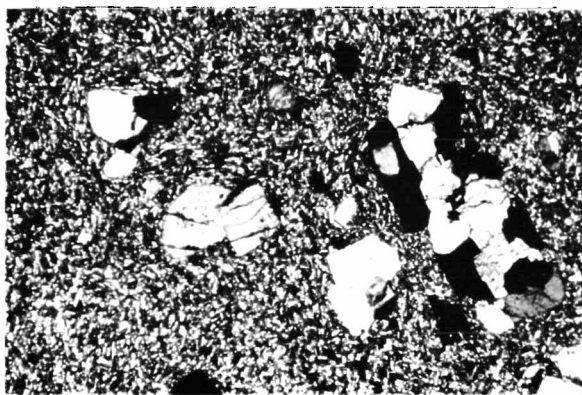


Figure 5. Thin section view of typical feldspar glomerocryst at 15x magnification under crossed nicols.

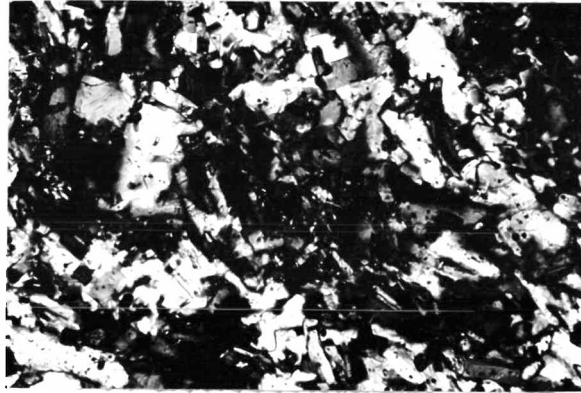


Figure 6. Thin section view of groundmass at 500x magnification under crossed nicols.

The chilled contact rocks are distinctive in thin section as well as in hand specimen. The phenocrysts of these specimens are as described above, but the groundmass is much finer grained, ranging from $<.001$ to $.05$ mm. in size and subhedral to anhedral in shape. Although pyroxene phenocrysts are present, they are not as common as in the unchilled rocks and the groundmass is noticeably deficient in pyroxene, both the granular and intergranular types. Flattened, primary vesicles up to one cm. long are occasionally noted in these rocks of the contact zone.

The alkali feldspar phenocryst and felsic groundmass materials account for more than 83 per cent of the bulk of these rocks. The phenocryst-to-groundmass ratio ranges from 1:3 to 1:6 over the mass. The alkali feldspar is seriate, ranging from $<.001$ to 4.6 mm. in size. Figure 7 gives the size distribution of these grains based on measurements of 600 grains. Modal analyses (Table 1) of this sodic microsyenite show that it contains on the average: 84 to 91 per cent alkali feldspar; < 1 to 10 per cent pyroxene,

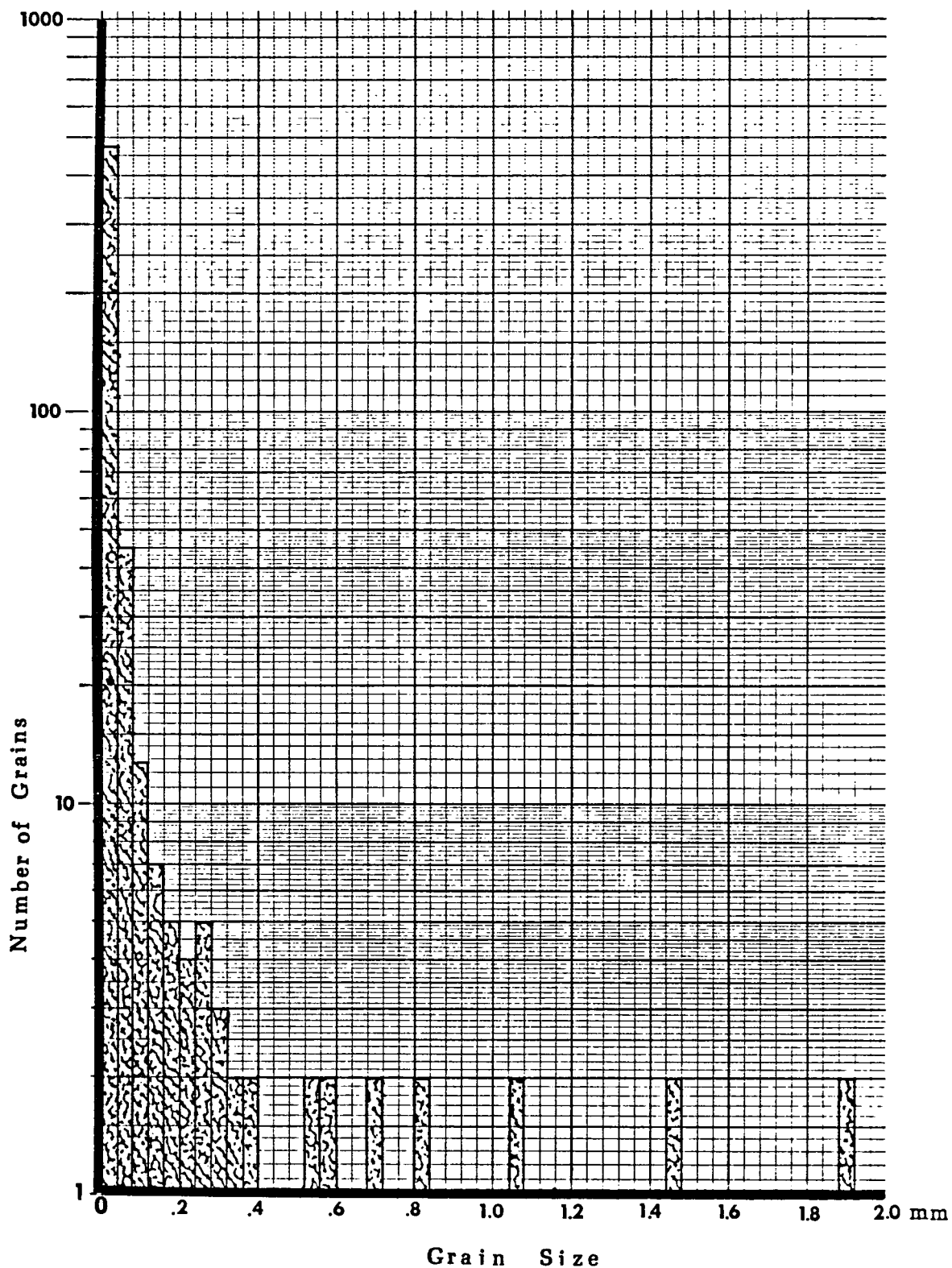


Figure 7. Semi-logarithmic plot of size distribution (number frequency) of alkali feldspar grains. Each horizontal space represents 0.04 mm.

TABLE 1. MODAL ANALYSES

Sample Number	Feldspar Pheno- crysts	Felsic Ground- mass	Pyroxene		Iron Oxides		Other ⁽³⁾	Quartz ⁽⁴⁾	Total	
			Pheno- crysts ⁽¹⁾	Ground ⁽²⁾ mass	Pheno- crysts	Ground- mass			Felsic	Mafic
C-6	17.6	68.1	0.5	9.1	0.3	1.6	0.8 (A,B,C)	1.2	85.7	11.2
D-1	19.8	67.0	0	0.2	0	10.0	3.0 (A,B,C)	6.2	86.8	10.2
D-11	19.2	69.8	0	8.0	0	1.6	1.4 (A,C,E)	0.9	89.0	9.6
D-18	19.0	72.6	0.6	5.0	0	1.8	1.0 (A,C)	1.1	91.6	7.4
Dam 1-2	16.2	71.6	0	0.2	0	5.8	6.2 (A,B,F)	1.8	87.8	6.0
E-3	19.2	65.8	0.6	10.0	0	3.4	1.0 (A,D)	0.7	85.0	14.0
E-24	24.8	63.3	0.7	7.5	1.1	1.7	0.5 (A)	1.7	88.1	10.5
G-1	12.4	70.4	0.2	3.8	0	4.8	8.4 (A)	2.9	82.8	8.8
H-5	23.2	60.4	0.6	9.0	0.8	3.0	3.2 (A)	0.9	83.6	13.4
L-9	27.4	62.2	0.8	5.6	0	2.6	1.4 (A,C,D)	1.1	89.6	9.0
L-15	17.4	67.4	0	10.0	0.6	2.2	2.4 (A,C)	2.4	84.8	12.8
IV-11	14.2	74.2	1.0	7.0	0	2.6	1.0 (A,C,F)	1.3	88.4	10.6
VI-3	20.6	67.4	0.2	5.2	0	2.6	4.0 (A,E)	2.7	88.0	8.0
VI-7	18.2	70.6	0	7.2	0.2	3.2	0.6 (A,C)	2.0	88.8	10.6
VI-11	19.3	70.3	0.4	6.0	0.2	2.9	0.9 (A,C)	1.2	89.6	9.5

(1) Grains > 0.3 mm. on maximum diagonal

(2) Combined quartz and feldspar grains < 0.3 mm. on maximum diagonal

(3) According to the following codes:

(A) Unidentified alteration products

(B) Secondary carbonate

(C) Zircon

(D) Riebeckite

(E) Altered olivine?

(F) Secondary quartz

(4) As calculated by x-ray diffraction. See Appendix 6 for details.

1.5 to 10 per cent iron oxides; < 1 to 6 per cent quartz; and trace amounts of zircon, riebeckite, and plagioclase.

Based on 15 modal analyses and examination of 200 thin sections, there are no significant, optically determined, primary variations in the rocks of this mass, other than as noted above.

The fresh rock is hard and dense (specific gravity = 2.720, Sample IV-11) with no detectable primary pores or voids except at the intrusive contacts. Small cracks and veinlets generally filled with cryptocrystalline quartz, carbonate or an unidentified amber-colored iron mineral are common in the moderate to intensely altered specimens (see Figure 8).

The alteration sequence appears to be:

1. Peripheral attack and corrosion of the pyroxene phenocrysts.

This liberates iron for local micro-scale iron staining of neighboring grains.

2. Further attack of pyroxene phenocrysts until they lose their color and the birefringence is masked by alteration residue (dull bronze-brown color). This stage is generally marked by iron stains visible in the hand specimen, either as (a) intense localized color bands and streaks along cracks and fractures, or (b) as a weak, blotchy staining that permeates the specimen (apparently around individual grains, but difficult to see in thin section).

3. Complete alteration of the pyroxene phenocryst to opaque iron minerals; slight attack and alteration of the groundmass pyroxene; very slight peripheral corrosion (or irregular marginal replacement) and breakdown of the alkali feldspar phenocrysts.

4. Further attack of the feldspar phenocryst which renders the rock porous; more complete alteration of the groundmass pyroxenes.



Figure 8. Thin section view showing quartz vein (light gray) in felsic groundmass (dark gray to black) at 60x magnification under crossed nicols.

5. Further alteration of the feldspar phenocrysts and alteration to, or replacement by, carbonate and/or quartz. Groundmass alkali feldspar phenocrysts generally show some decomposition by this stage. All groundmass pyroxenes altered to opaque minerals. Iron staining deep and intense.

6. Complete alteration of almost all of the primary groundmass pyroxenes and feldspars; generally this stage is marked by a decrease in the degree of iron staining as if bleaching were taking place. Rocks altered to this degree are chalky and crumbly; no mineral grains larger than 0.1 mm. generally remain.

Some, or all, of these changes could be in part due to deuteric or late hydrothermal alteration as well as subaerial weathering, and no criteria are present for adequate assessment of the relative importance of these effects.

ALKALI FELDSPARS

Description

Cryptoperthitic polymorphs of alkali feldspar form the bulk of this intrusive igneous mass and give it most of its distinctive characteristics. For this reason, most of the effort in this work has been expended on the study of these minerals. Both optical and x-ray investigations were conducted, but since the x-ray techniques provide the most precise data, this aspect of the study was emphasized.

The feldspar grains from the main mass are generally fresh and relatively free of alteration, whereas many of the samples from the prongs are highly altered. The unaltered grains are generally clean and crisp even though some appear to have been slightly resorbed. The (001) and (010) cleavages are well displayed although differentiation of the two cleavages is difficult.

The phenocrysts (arbitrarily selected at 0.3 mm. or larger) compose 14 to 27 per cent (average 19 per cent) and the felsic groundmass grains (includes quartz) 60 to 73 per cent (average 69 per cent) of the total rock based on modal analyses (Table 1). The phenocryst-to-groundmass ratio varies nonsystematically between these limits over the mass.

Based on a fixed-stage count of 500 phenocryst grains:

48% are anhedral

47% are subhedral and

5% are euhedral;

30% occur as single grains,

31% occur as multiple grains (glomerocryst aggregates of 2 to 6 individual grains) and

39% occur as glomerocrysts (7 or more grains in an aggregate);

31% are twinned and
69% show no twinning;

23% are elongate and
77% are blocky;

64% contain inclusions and
36% contain no inclusions;

of the grains which contain inclusions,

66% contain only minute inclusions near the grain periphery and
34% contain either peripheral inclusions and center inclusions
or center inclusions alone;

4% of the grains display zoning phenomena (approximately 60%
display zoning phenomena on a Universal-stage) and
96% show no zoning.

There appears to be no preferential grain size, orientation, or grain type within the aggregated groups (multiple grains and glomerocrysts) nor are any indications of high pressure formation (interpenetrating or distorted grains) apparent. Of the twinned grains, most appear to be twinned according to the Carlsbad law, but no detailed study of the twinned types was made.

The larger inclusions or intergrowths present are commonly pyroxene or other alkali feldspar grains and rarely iron oxide grains. The small peripheral inclusions so prevalent consist of minute (approximately .01 mm.) subhedral and euhedral crystals of the light-green pyroxene material (see Figure 9).

Zoning is rarely observed on the fixed stage microscope, but on the U-stage most grains display some degree of zoning. In all instances the zoning is from a higher 2Vx value at the center to a lower value at the periphery. Careful examination shows the zoning generally to be rather blotchy and irregular.

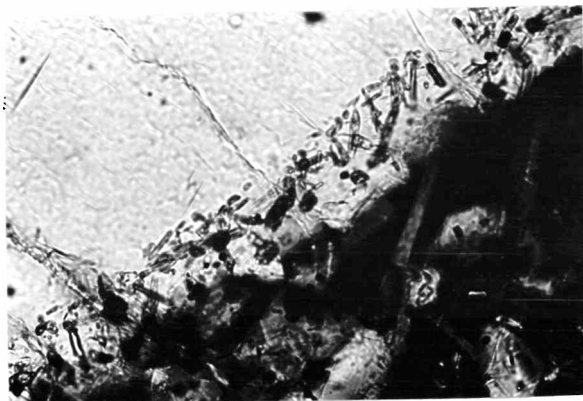


Figure 9. Thin section view of feldspar phenocryst (gray) grain periphery and minute pyroxene inclusions at 500x under crossed nichols.

All alkali feldspar grains (phenocrysts and groundmass) have thin rims encasing (or partially enclosing) each grain. The rim varies from imperceptible up to approximately .01 mm. thick and is not necessarily of

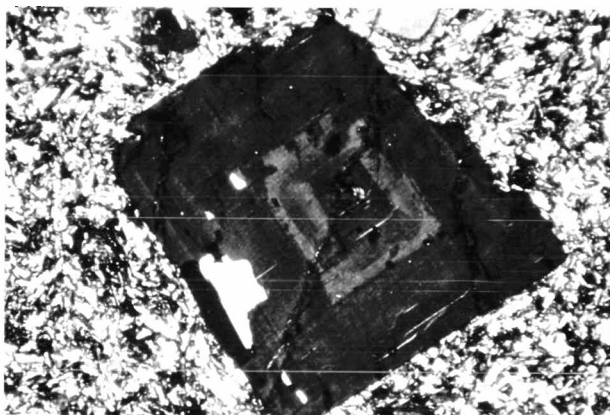


Figure 10. Thin section view of zoned feldspar phenocryst at 30x magnification.

uniform thickness on any one grain. The rim normally has a lower $2V_x$ than the core of the grain which it coats. This rim represents a small fraction of the total bulk of the phenocryst grains, but may represent as much as 30 per cent of the volume of many groundmass grains.

2V Determinations

The results of 138 2V determinations made on 14 samples are presented in Tables 2 and 3 and combined with composition data in Figures 11 and 12. Figure 13 shows the location of the samples which were chosen for 2V determination. Criteria for selecting these particular samples were:

- (1) to sample the periphery and center portions of the
main mass;
- (2) to get ample spatial coverage of the masses; and
- (3) to select only fresh, unaltered samples.

Numerous attempts at gathering additional 2V data from the north prong and much of the south prong were unsuccessful due to feldspar alteration.

The 2V's range from a minimum of 18° to a maximum of 57° . In all instances the optic plane is perpendicular to (010).

The phenocrysts (92 determinations) range from a $2V_x$ of 27° to 57° with an average maximum and minimum of 49° and 36° respectively. For all samples measured the phenocrysts average 42° $2V_x$ with a 13° difference between maximum and minimum $2V_x$ per sample. Zoning ranges from almost imperceptible to a maximum of 25° $2V_x$ in any one grain. The greatest zoning range detected was from 57° in the core through 48° in the mantle to 32° in the rim of a grain from sample D-11.

The groundmass (46 determinations) ranges from a $2V_x$ of 18° to 50° with an average maximum and minimum of 44° and 33° respectively. For

TABLE 2. 2V DETERMINATIONS

Sample Number	Type	No. of Determ.	Maximum 2V _x	Minimum 2V _x	Zoning of 2V			Maximum Zoning of 2V Detected
					Core	Mantle	Rim	
D-1	Phen GM	6	49.2	41.8	47.3	-	42.7	4.6
		3	46.1	32.8	46.1	-	39.4	6.7
D-4	Phen GM	3	49.0	48.6				
		4	48.1	37.7	46.3	-	40.2	
D-11	Phen GM	16	57.3	31.7	57.3	47.1	32.5	24.8
		11	47.7	32.0	47.0	-	32.1	14.9
D-12	Phen GM	7	49.5	27.1	40.3	-	27.1	13.6
		6	49.9	18.5	32.2	-	18.5	13.7
D-14	Phen GM	3	50.2	45.4	50.2	-	46.3	3.9
		3	41.3	36.5				
D-22	Phen GM	3	50.1	37.2	45.5	-	37.2	8.3
		3	46.7	40.0				
Dam-3	Phen GM	6	38.9	35.5				
		3	36.0	29.8				
E-4	Phen GM	7	48.4	34.1	45.4	-	39.6	5.8
		3	42.6	32.1				
G-3	Phen GM	5	49.6	39.6	45.2	-	39.6	5.6
		3	40.2	36.1				
G-18	Phen GM	5	49.7	43.1	47.2	-	43.1	4.1
		4	40.1	32.1				
K-2	Phen GM	4	47.4	36.1	46.1	-	37.8	8.3
		3	42.1	31.0				
I-2	Phen GM	13	46.0	43.1	46.4	-	43.1	3.3
			Too Fine to Measure					
VI-1	Phen GM	10	47.0	37.5	42.0	-	48.5	6.5
			Too Fine to Measure					
VI-11	Phen	4	52.7	49.8				

all samples analyzed the groundmass averages 38° 2Vx with an 11° difference between maximum and minimum 2Vx per sample. Zoning ranges from almost imperceptible to a maximum of 15° in any one grain.

Although 138 determinations are not sufficient in number to provide a statistical sampling of these rocks, some trends are evident. There is generally overlap between phenocrysts and groundmass 2V's for any sample (D-4, D-14, and G-18 are exceptions to this statement). Both phenocrysts and groundmass population have a maximum deviation of $\pm 12.1^{\circ}$ 2Vx about their median values. Phenocrysts maximum, minimum and average 2Vx values are larger than corresponding groundmass values for all samples except D-12. Phenocryst samples toward the center of the main mass appear to have larger maximum 2Vx values than samples near or on the periphery. The single prong sample has 2Vx values less than all others.

Figure 12 shows the samples examined to cluster around the low sanidine series. The samples of this study would thus provide excellent materials for detail refinement of the 2V versus per cent Or composition variations in this region of alkali feldspar compositions.

Composition Analyses

The alkali feldspar composition analyses of this study were determined by x-ray diffraction methods. The analysis techniques, which result in percentage of Orthoclase (stated % Or) present, are based on the work of Orville (1967), and Tuttle and Bowen (1958). Simply stated, the angular separation between the $\bar{2}01$ alkali feldspar peak and an internal standard peak are measured and converted to % Or using the published data. This method of alkali feldspar composition analysis is reported to have an accuracy of ± 1.5 mole % Or (Orville, 1963, p. 206). Details of this analytical technique are discussed in Appendix 3.

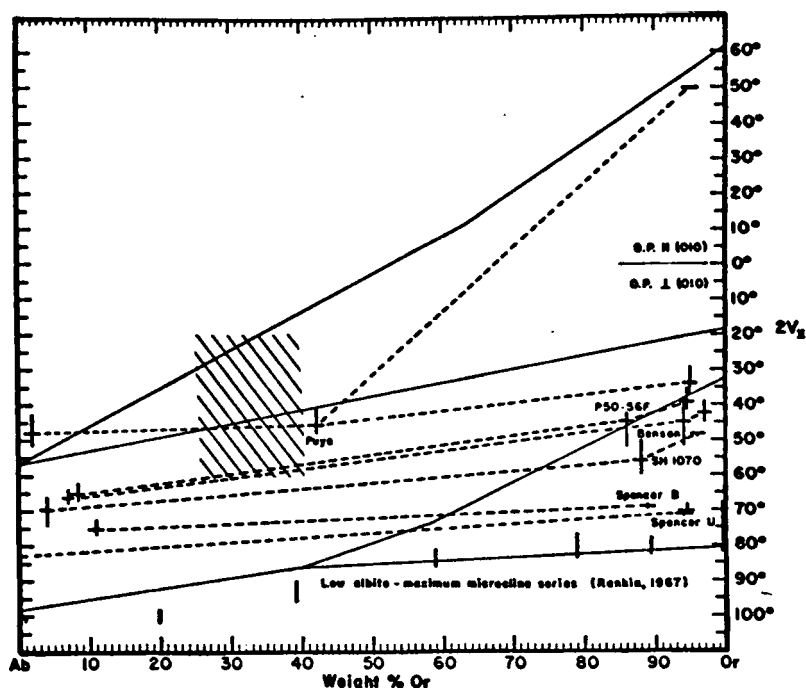


Figure 11. $2V_x$ plotted against Or content for alkali-exchanged feldspars. Light solid lines are series of Tuttle (1952) and MacKenzie and Smith (1955) from top to bottom as follows: high sanidine, low sanidine, orthoclase, maximum microcline. Heavy dashed lines connect $2V_x$ measurements on feldspars of equivalent structural state. Symbols are drawn as a vertical bar representing the range of $2V_x$ intersected by a horizontal bar at the average $2V_x$. After Wright and Stewart (1968, Figure 4, p. 56). The diagonal shaded portion of this figure is enlarged in Figure 12.

Each composition analysis attempted in this study was graded according to its apparent quality. Peak sharpness (shape) and angular separation reproducibility (range) were the two criteria used in the quality assessment. Thus acceptable analyses have C, B, or A designations, whereas unacceptable analyses have D or F designations for either shape or range. Details of this data quality assessment and examples are presented in Appendix 7.

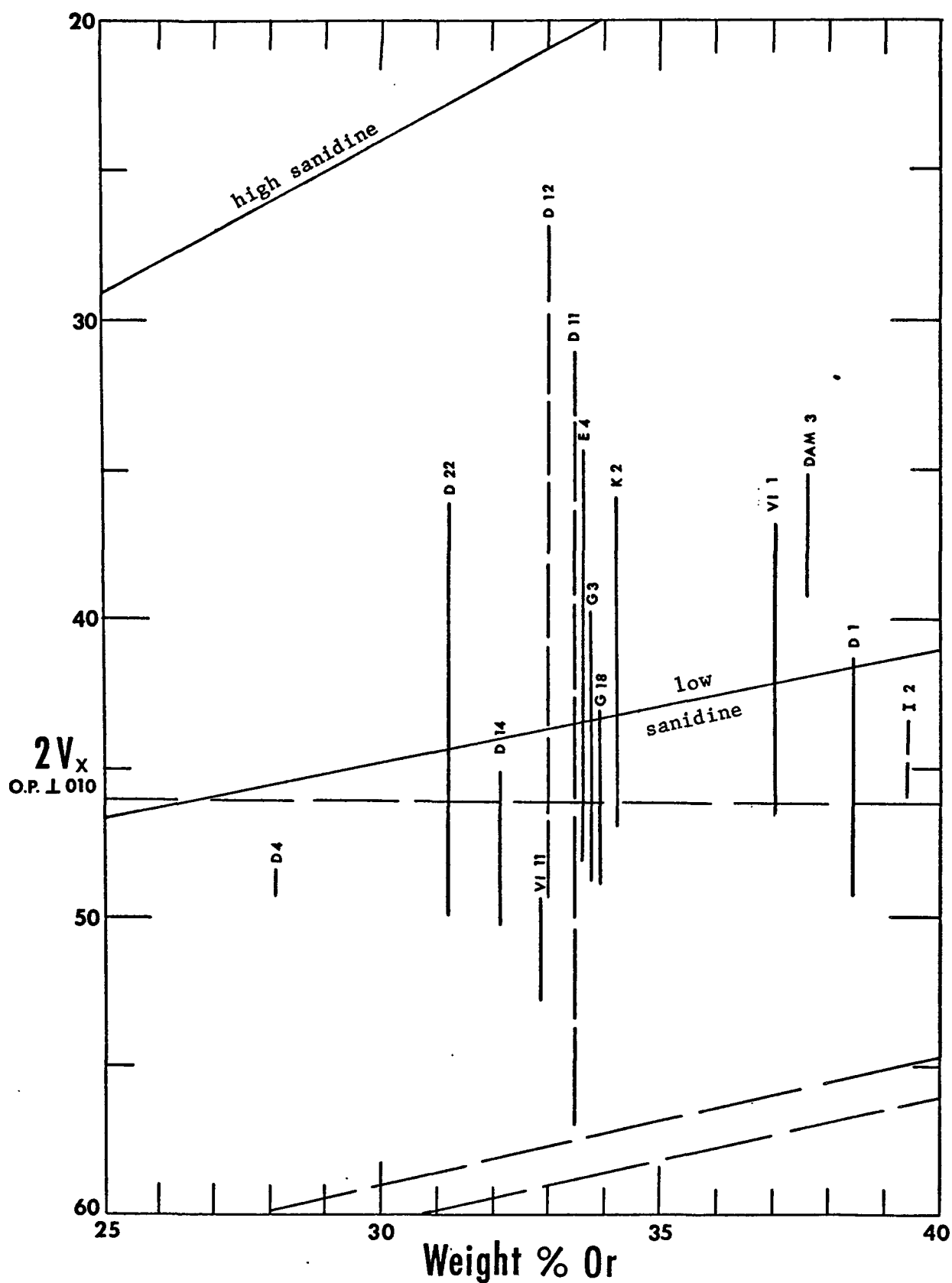


Figure 12. $2V$ range plotted against Or content for the phenocryst samples of this study (data from Tables 2 and 4). Dashed vertical lines are plotted using compositions inferred from nearby rocks.

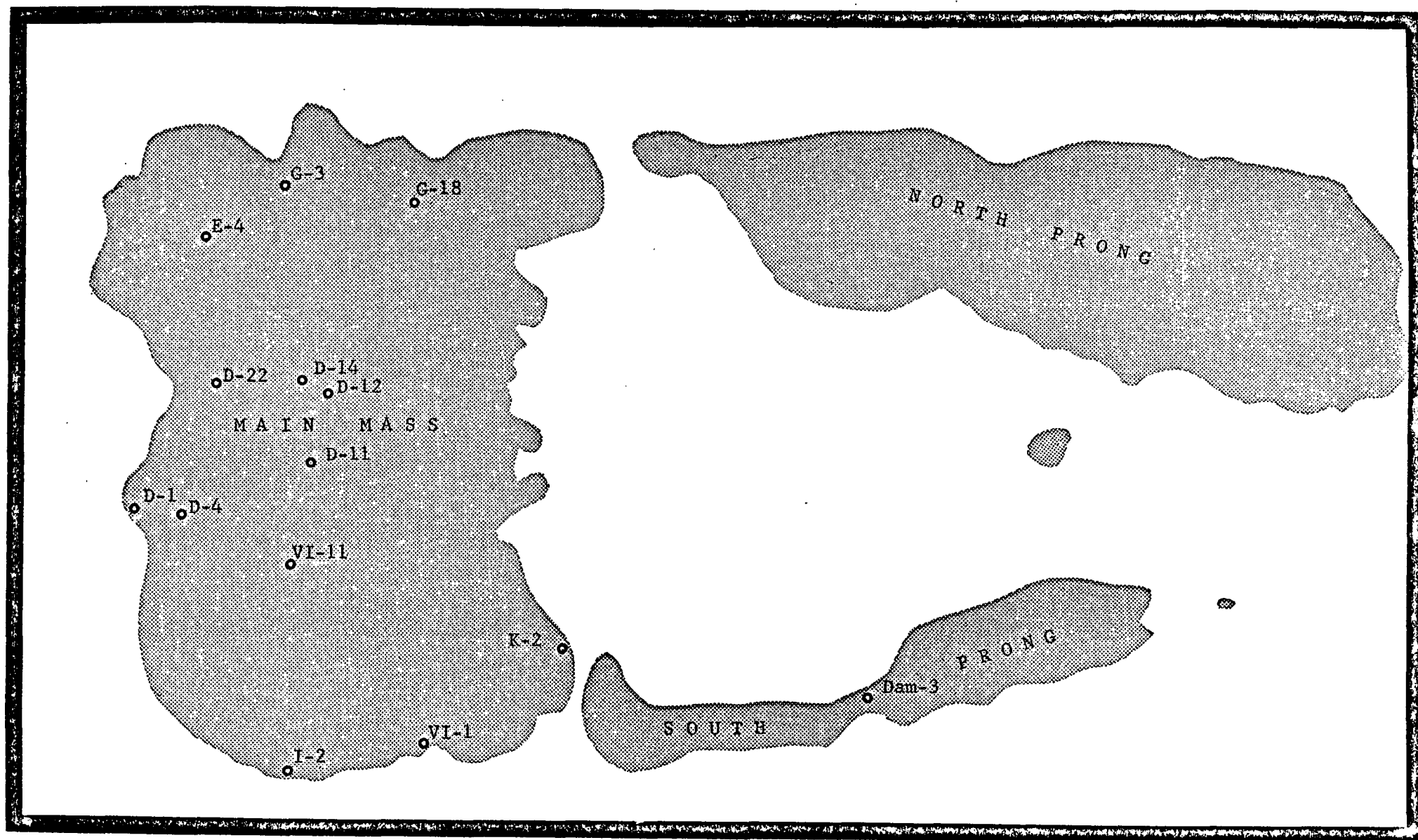


Figure 13. Location of 2V Samples.

TABLE 3
Summation of 2Vx Determinations

	<u>Number of Analyses</u>	<u>Range of 2Vx</u>	<u>Average Maximum 2Vx per Sample</u>	<u>Average Minumum 2Vx per Sample</u>	<u>Median 2Vx All Samples</u>	<u>Standard Deviation of 2Vx All Samples</u>
Phenocrysts	92	27.1°-57.3°	48.9°	35.8°	42.3°	6.1°
Groundmass	46	18.5°-49.9°	43.7°	32.6°	38.1°	5.7°

Of the 134 composition analyses attempted for this study, 102 (76 per cent) gave acceptable results. Unacceptable results are primarily the result of sample impurity or inhomogeneity.

These 134 analyses are tabulated in Table 4 (phenocryst samples) and Table 5 (groundmass samples). In these tables the samples are arranged in alphabetical, then numerical sequence. For each analysis the following data are presented:

- (a) Type of internal standard: KBrO_3 for the Orville (1967) method, or Quartz for the Tuttle and Bowen (1958) method.
- (b) Number of runs: the number of angular separation scans and measurements between the $\bar{2}01$ feldspar peak and the standard peak.
- (c) Averaged $\Delta 2\theta$: the average (in degrees 2θ) angular separation between the $\bar{2}01$ feldspar peak and the standard peak for this sample.
- (d and e) Maximum and minimum $\Delta 2\theta$ observed.
- (f and g) Angular separation range and peak shape quality assessments.
- (h) Mole per cent orthoclase as derived from Figure 32 or 33 of Appendix 3 based on the average $\Delta 2\theta$ calculation.

The calculation of these analyses to mole per cent rather than weight per cent orthoclase is in accord with most of the recent published works on alkali feldspars.

Summary of Composition Data

Phenocrysts: A total of 114 phenocryst analyses were attempted, of which 90 (79%) gave acceptable results. Based on the acceptable data (as are all figures which follow), the phenocryst samples are seen to

vary from a minimum of 28.5 to a maximum of 41.4 mole % Or. The median phenocryst composition is 34.7 mole % Or.

The spatial distribution of these composition determinations is shown on Figure 14. In this figure the phenocryst compositions, which are rounded to the nearest whole percentage, are shown as an overlay from Figure 2, the sample location map. Careful examination of these composition distributions and regrouping of the data from Table 4 (by sample location) allows the following salient points to appear (as summarized in Table 6):

Main Mass Samples:

1. 90 analyses were attempted, of which 73 (81%) gave acceptable results.
2. The minimum, maximum, and median phenocryst compositions are 31, 40, and 34 mole % Or respectively.
3. There is a definite trend from high composition values at the periphery to lower values toward the center.
4. All samples with phenocryst compositions greater than 36 mole % Or occur at, or very near the periphery.
5. Subdivision of the samples from the main mass into two categories based on phenocryst compositions is possible and provides the following data:

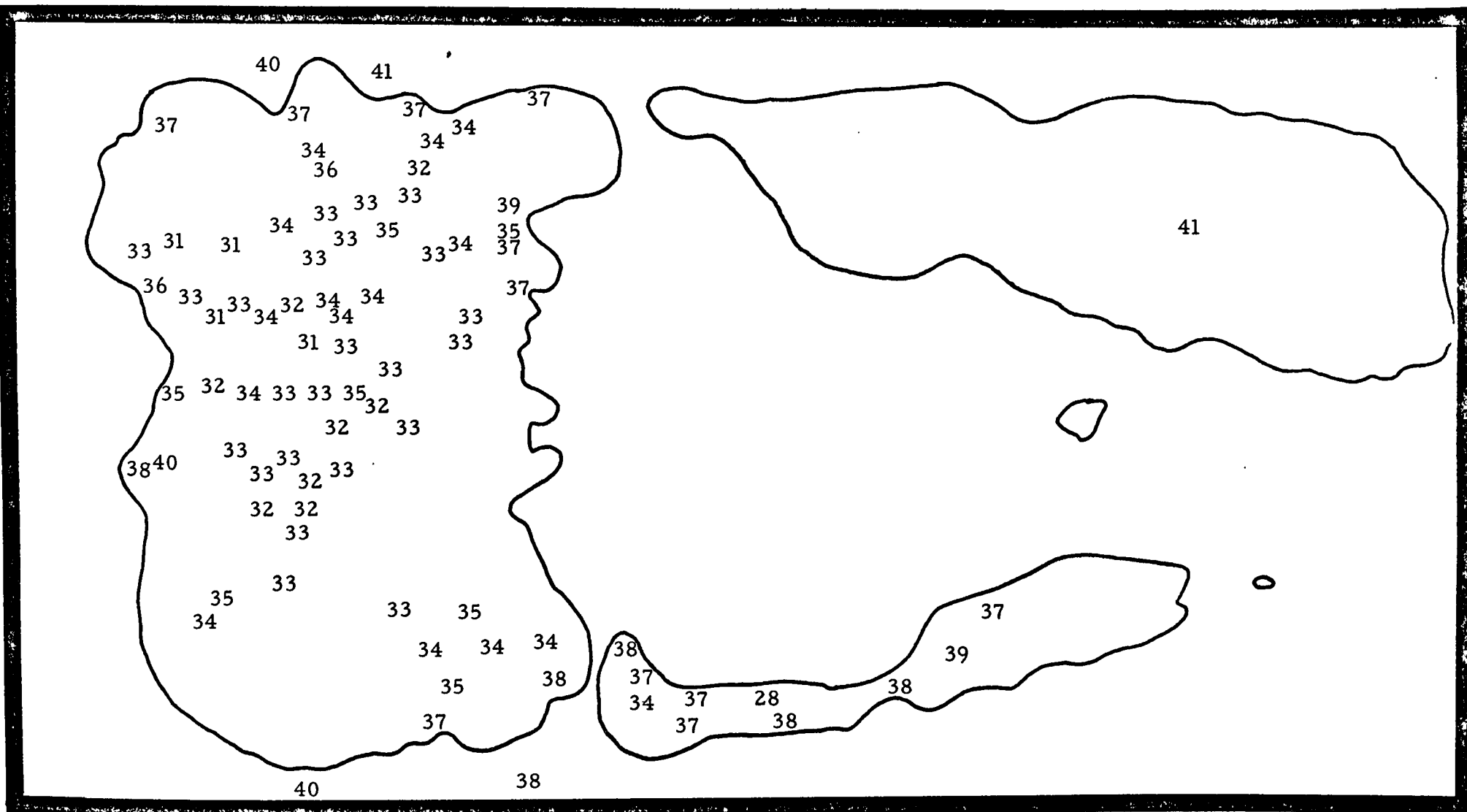


Figure 14. Spatial distribution of Phenocryst Composition Determinations. Data from Table 4 on an overlay of Figure 2 (Sample Location Map). Acceptable analyses are shown rounded to the nearest whole percentile.

Location	Samples with ⁽¹⁾ <u>< 36 mole % Or</u>	Samples with ⁽²⁾ <u>> 36 mole % Or</u>
	Near periphery to core	At or very near periphery
No. of Analyses	78	12
No. of Acceptable Results	64	9
% Acceptable Results	82	75
Maximum mole % Or	36	40
Minimum mole % Or	31	36
Median mole % Or	33	38

Figure 15 shows the frequency distribution curve for all acceptable main mass analyses. Note the definite bimodal distribution with a minimum at approximately 36 mole % Or.

Prong Samples:

1. Of the 17 south prong analyses attempted, 12 (71%) gave acceptable results. The minimum, maximum and median phenocryst compositions are 28, 39, and 36 mole % Or respectively. Sample I-14 is anomalously low (28 mole % Or) by comparison with all other analyses performed, and may be erroneous.

2. Of 3 north prong analyses attempted, a single

(1) Hereafter referred to as the main mass core samples.

(2) Hereafter referred to as the main mass periphery samples.

one (Sample V-5) gave acceptable results.

Numerous attempts at additional north prong analyses were unsuccessful due to the very poor preservation state of the feldspars from this locality.

3. With two exceptions (Samples I-14 and H-7) the prong samples have compositions in the same range as the peripheral samples of the main mass.

Dike Samples:

1. The high success ratio (100%) for these four samples is due to meticulous hand picking of the phenocryst for analysis. The four samples had a minimum, maximum, and median of 38, 41, and 40 mole % Or respectively.
2. The dike samples have composition ranges similar to, but slightly higher than, the main mass periphery samples and the prong samples.

Groundmass: A total of 12 groundmass composition analyses were attempted, and all gave acceptable results. The minimum, maximum, and median values are 40, 46, and 41 mole % Or respectively.

Main Mass Samples:

1. A total of 9 groundmass analyses were run with minimum, maximum, and median compositions of 40, 46, and 42 mole % Or respectively.
2. Subdividing these 9 samples according to their location in the main mass gives:

	<u>Core Samples</u>	<u>Periphery Samples</u>
Number of Analyses	7	2
Maximum mole % Or	46	40
Minimum mole % Or	40	40
Median mole % Or	42	40

Thus the main mass core groundmass samples may have slightly higher mole % Or compositions than the periphery samples, but additional analyses must be run before this point can be proven.

Prong Samples:

1. Three south prong groundmass analyses were run which gave minimum, maximum, and median mole % Or compositions of 40, 44, and 42 respectively. Again, additional analyses will be required in order to be certain that these are truly representative values for these rocks.

No groundmass composition analyses were run on the dike samples or the north prong for this study. These should certainly be included with the additional groundmass samples recommended above for extension of this study.

TABLE 4: PHENOCRYST COMPOSITION ANALYSES

Sample Number	Type of Standard	Number of Runs	$\Delta 2\theta$ (201 Feldspar-Standard)			Data	Quality	Mole Per Cent Or
			Average	Maximum	Minimum	Range	Shape	
A-25	KBrO ₃	6	1.354	1.374	1.333	B	D	40.3
B-1	KBrO ₃	6	1.368	1.377	1.355	B	C	39.0
B-4	KBrO ₃	15	1.395	1.410	1.375	C	C	36.6
B-10	KBrO ₃	6	1.409	1.424	1.400	B	D	35.3
B-13	KBrO ₃	6	1.185	1.208	1.166	C	F	55.7
B-15	KBrO ₃	6	1.350	1.378	1.319	D	F	40.7
B-20	KBrO ₃	6	1.377	1.391	1.370	B	D	38.2
B-23	KBrO ₃	4	1.321	1.329	1.312	A	D	43.3
B-25	KBrO ₃	6	1.285	1.292	1.275	B	D	46.6
C-1	KBrO ₃	6	1.437	1.445	1.427	B	D	32.7
C-2	KBrO ₃	6	1.421	1.424	1.416	A	B	34.2
C-4	KBrO ₃	6	1.416	1.432	1.405	B	C	34.7
C-5	KBrO ₃	6	1.419	1.435	1.390	C	D	34.4
C-6	KBrO ₃	6	1.423	1.446	1.402	C	D	34.0
C-9	KBrO ₃	6	1.441	1.446	1.435	A	C	32.4
C-10	KBrO ₃	7	1.444	1.452	1.433	B	C	32.4
C-11	KBrO ₃	10	1.411	1.429	1.404	B	C	35.1
C-12	KBrO ₃	8	1.438	1.452	1.428	B	C	32.7
C-13	KBrO ₃	6	1.434	1.449	1.412	C	C	33.0
C-14	KBrO ₃	9	1.420	1.437	1.404	B	C	34.3
C-15	KBrO ₃	10	1.446	1.458	1.429	B	D	31.9
C-16	KBrO ₃	7	1.446	1.455	1.437	B	B	31.9
C-17	KBrO ₃	9	1.441	1.456	1.431	B	C	32.4
C-18	KBrO ₃	9	1.417	1.430	1.402	B	C	34.6
C-19	KBrO ₃	6	1.394	1.440	1.363	D	C	36.7

TABLE 4: PHENOCRYST COMPOSITION ANALYSES, CONTINUED

Sample Number	Type of Standard	Number of Runs	$\Delta 2\theta$ (201 Feldspar-Standard)			Data Quality		Mole Per Cent Or
			Average	Maximum	Minimum	Range	Shape	
Dam 1-2	Quartz	6	0.718	0.730	0.710	B	B	37.9
Dam 3	Quartz	6	0.722	0.730	0.712	B	B	37.6
Dam 5	Quartz	6	0.732	0.737	0.725	A	B	36.7
D-1	KBrO ₃	4	1.375	1.388	1.359	B	C	38.4
D-2	KBrO ₃	8	1.362	1.370	1.351	B	C	39.6
D-4	KBrO ₃	6	1.488	1.502	1.475	B	D	28.1
D-5	KBrO ₃	7	1.431	1.447	1.421	B	C	33.3
D-6	KBrO ₃	6	1.417	1.432	1.401	B	D	34.6
D-7	KBrO ₃	6	1.432	1.441	1.418	B	B	33.2
D-8	KBrO ₃	6	1.436	1.454	1.423	B	C	32.9
D-10	KBrO ₃	6	1.429	1.437	1.416	B	C	33.5
D-14	KBrO ₃	6	1.444	1.459	1.424	B	C	32.1
D-17	KBrO ₃	7	1.425	1.441	1.403	C	C	33.9
D-20	KBrO ₃	6	1.437	1.456	1.423	B	C	32.8
D-22	KBrO ₃	7	1.454	1.467	1.442	B	B	31.2
D-24	KBrO ₃	6	1.421	1.432	1.407	B	C	34.2
E-2	KBrO ₃	9	1.406	1.436	1.392	C	D	35.6
E-3	KBrO ₃	7	1.406	1.419	1.392	B	D	35.6
E-4	KBrO ₃	7	1.428	1.446	1.418	B	D	33.6
E-6	KBrO ₃	7	1.423	1.439	1.409	B	C	34.0
E-8	KBrO ₃	6	1.430	1.432	1.427	A	B	33.4
E-11	KBrO ₃	6	1.432	1.441	1.420	B	C	33.2
E-12	KBrO ₃	6	1.436	1.441	1.429	A	B	32.9
E-14	KBrO ₃	6	1.421	1.438	1.400	C	C	34.2
E-16	KBrO ₃	6	1.431	1.439	1.421	A	C	33.3
E-17	KBrO ₃	6	1.423	1.434	1.406	B	C	34.0
E-20	KBrO ₃	6	1.371	1.392	1.365	B	C	38.8

TABLE 4: PHENOCRYST COMPOSITION ANALYSES, CONTINUED

Sample Number	Type of Standard	Number of Runs	$\Delta 2\theta$ (201 Feldspar-Standard)			Data Quality		Mole Per Cent Or
			Average	Maximum	Minimum	Range	Shape	
G-1	KBrO ₃	6	1.392	1.403	1.383	B	F	36.9
G-1/2	KBrO ₃	11	1.390	1.408	1.376	B	C	37.0
G-3	KBrO ₃	8	1.426	1.449	1.404	C	C	33.8
G-7	KBrO ₃	7	1.446	1.463	1.430	B	D	32.0
G-9	KBrO ₃	10	1.400	1.409	1.393	A	C	36.1
G-11	KBrO ₃	6	1.429	1.434	1.421	A	C	33.5
G-13	KBrO ₃	6	1.411	1.423	1.404	B	B	35.1
G-15	KBrO ₃	7	1.432	1.450	1.413	C	C	33.2
G-16	KBrO ₃	7	1.461	1.476	1.434	C	C	30.6
G-18	KBrO ₃	7	1.426	1.437	1.412	B	B	33.8
G-20	KBrO ₃	11	1.420	1.434	1.394	C	C	34.3
G-20f	KBrO ₃	7	1.390	1.399	1.373	B	B	37.0
H-5	KBrO ₃	6	1.390	1.408	1.381	B	C	37.0
H-7	KBrO ₃	7	1.420	1.430	1.410	B	C	34.3
J-1	KBrO ₃	6	1.369	1.382	1.353	B	D	38.9
J-4	KBrO ₃	8	1.371	1.388	1.358	B	F	38.8
J-6	KBrO ₃	9	1.425	1.441	1.399	C	C	33.9
K-2	KBrO ₃	14	1.421	1.442	1.401	C	C	34.2
K-3	KBrO ₃	12	1.419	1.435	1.407	B	D	34.4

TABLE 4: PHENOCRYST COMPOSITION ANALYSES, CONTINUED

Sample Number	Type of Standard	Number of Runs	$\Delta 2\theta$ (201 Feldspar-Standard)			Data Quality		Mole Per Cent Or
			Average	Maximum	Minimum	Range	Shape	
L-1	KBrO ₃	7	1.407	1.436	1.386	C	F	35.5
L-2	KBrO ₃	10	1.426	1.439	1.410	B	D	33.8
L-3	KBrO ₃	9	1.430	1.441	1.422	B	D	33.4
L-4	KBrO ₃	7	1.430	1.440	1.421	B	C	33.4
L-5	KBrO ₃	6	1.447	1.452	1.443	A	C	31.9
L-8	KBrO ₃	6	1.426	1.431	1.420	A	A	33.8
L-9	KBrO ₃	5	1.420	1.433	1.408	B	C	34.3
L-12	KBrO ₃	7	1.423	1.433	1.417	A	B	34.1
L-13	KBrO ₃	6	1.420	1.444	1.409	C	D	34.3
L-14	KBrO ₃	6	1.382	1.391	1.365	B	C	37.8
L-15	KBrO ₃	6	1.380	1.397	1.353	C	D	37.9
L-17	KBrO ₃	7	1.434	1.424	1.435	A	C	33.0
I-4	Quartz	6	0.702	0.705	0.695	A	B	39.3
I-6	Quartz	6	0.716	0.710	0.722	A	C	38.1
I-10	Quartz	6	0.718	0.708	0.726	B	B	37.9
I-11	Quartz	6	0.733	0.740	0.730	B	C	36.6
I-12	Quartz	6	0.714	0.730	0.705	B	A	38.2
I-14	Quartz	5	0.827	0.837	0.817	B	B	28.5
I-15	KBrO ₃	6	1.394	1.403	1.388	A	B	36.7
I-16	Quartz	6	0.717	0.723	0.707	A	A	38.0
II-1	Quartz	6	0.731	0.740	0.730	A	B	36.8
II-3	Quartz	7	0.688	0.692	0.682	A	C	40.5
II-5	Quartz	6	0.677	0.685	0.672	A	C	41.4
III-1	Quartz	6	0.733	0.737	0.725	A	B	36.6
III-2	Quartz	6	0.750	0.735	0.772	C	B	35.1

TABLE 4: PHENOCRYST COMPOSITION ANALYSES, CONTINUED

Sample Number	Type of Standard	Number of Runs	$\Delta 2\theta$ (201 Feldspar-Standard)			Data Quality		Mole Per Cent Or
			Average	Maximum	Minimum	Range	Shape	
IV-1	Quartz	7	0.796	0.802	0.787	A	C	31.2
IV-5	Quartz	6	0.797	0.805	0.795	A	C	31.1
IV-7	Quartz	6	0.778	0.792	0.767	B	C	32.7
IV-9	Quartz	6	0.741	0.752	0.730	A	B	35.9
IV-11	Quartz	9	0.775	0.785	0.770	A	B	32.9
V-5	KBrO ₃	6	1.343	1.352	1.329	A	C	41.3
V-7	Quartz	6	0.738	0.742	0.732	A	B	36.2
VI-1	Quartz	7	0.722	0.727	0.717	A	B	37.5
VI-3	Quartz	7	0.756	0.762	0.747	A	B	34.6
VI-5	Quartz	6	0.761	0.765	0.760	A	C	34.2
VI-7	Quartz	6	0.777	0.782	0.767	A	B	32.8
VI-9	Quartz	7	0.773	0.780	0.767	B	C	33.2
VI-11	Quartz	6	0.776	0.780	0.775	A	B	32.9
VI-13	Quartz	6	0.781	0.785	0.777	A	B	32.5
VI-15	Quartz	6	0.784	0.790	0.780	A	C	32.2
VI-17	Quartz	7	0.789	0.792	0.782	A	C	31.8
VI-19	Quartz	6	0.774	0.770	0.780	A	C	33.1
VI-21	Quartz	6	0.773	0.777	0.772	A	B	33.2
VI-23	Quartz	6	0.778	0.767	0.790	B	C	32.7

TABLE 5: GROUNDMASS COMPOSITION ANALYSES

Sample Number	Type of Standard	Number of Runs	$\Delta 2\theta$ (201 Feldspar-Standard)			Data Quality		Mole Per Cent Or
			Average	Maximum	Minimum	Range	Shape	
I-14	Quartz	6	0.650	0.652	0.625	B	B	43.8
I-12	Quartz	6	0.694	0.702	0.680	B	A	40.0
I-15	Quartz	6	0.691	0.697	0.682	A	B	40.2
I-15	KBrO ₃	11	1.319	1.350	1.295	D	D	43.5
II-1	Quartz	6	0.690	0.700	0.680	B	B	40.3
IV-3	Quartz	7	0.673	0.682	0.667	A	C	41.8
IV-9	Quartz	7	0.694	0.707	0.690	A	C	40.0
IV-11	Quartz	6	0.689	0.707	0.690	A	C	40.4
VI-3	Quartz	6	0.692	0.700	0.680	B	C	40.1
VI-11	KBrO ₃	8	1.330	1.337	1.325	A	C	42.5
VI-13	KBrO ₃	2	1.361	1.371	1.351	B	C	39.7
VI-15	KBrO ₃	6	1.287	1.299	1.266	B	C	46.4
VI-17	KBrO ₃	6	1.323	1.330	1.311	B	C	43.1

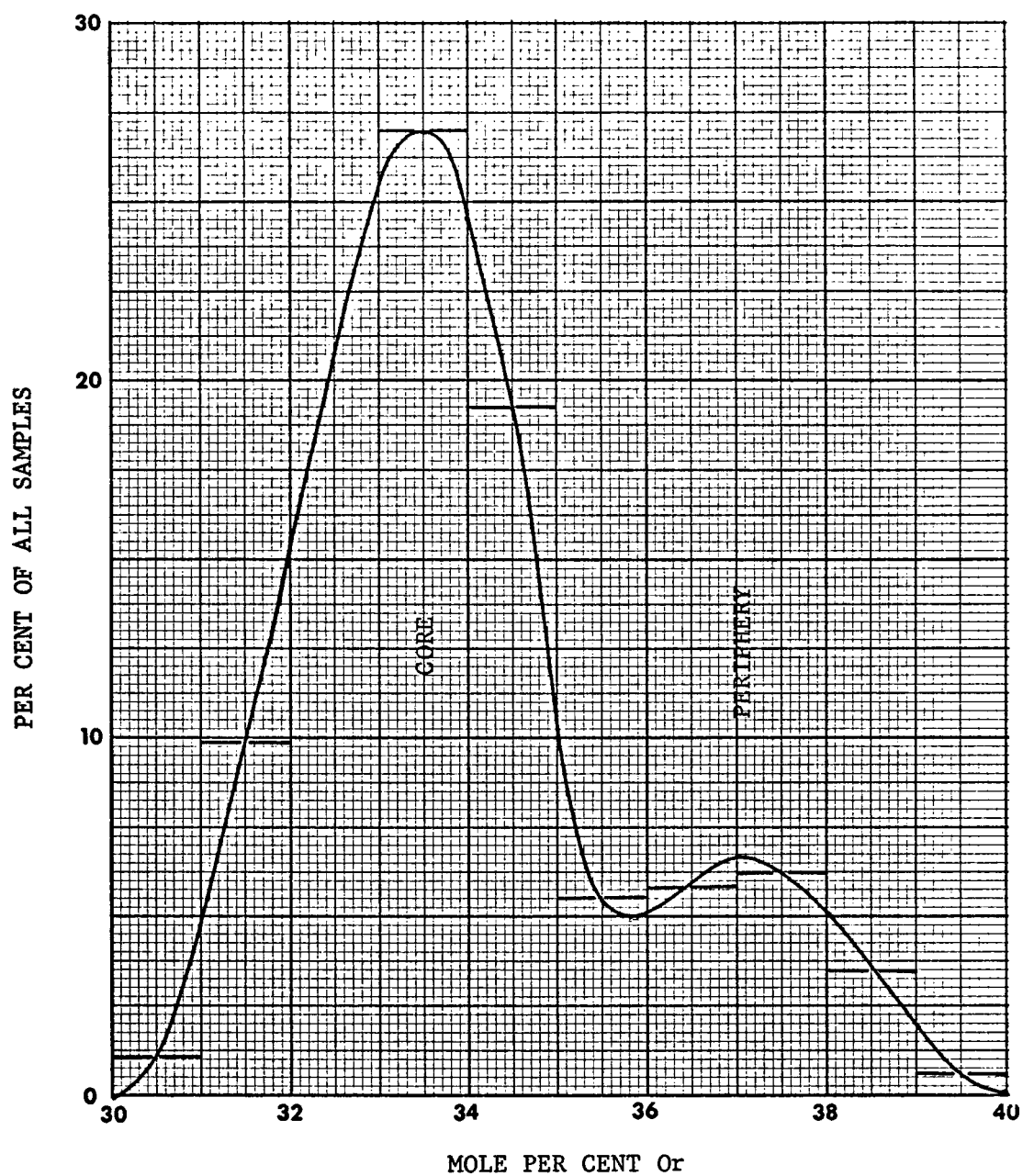


Figure 15. Frequency curve of all acceptable phenocryst composition analyses from the main mass.

Table 6. Summary of
Acceptable Composition Analysis Data

	Phenocryst Samples						Groundmass Samples					
	All Samples	Main Mass		Prongs		Dike Samples	All Samples	Main Mass		Prongs		Dike Samples
		Periphery	Core	South	North			Periphery	Core	South	North	
Number of Analyses	114	12	78	17	3	4	12	2	7	3	0	0
Acceptable Analyses	90	9	64	12	1	4	12	2	7	3		
% Acceptable	79%	75%	82%	71%	33%	100%	100%	100%	100%	100%		
Minimum Mole % Or	28.5	36.5	30.6	28.5	—	38.1	39.7	40.0	39.7	40.0		
Maximum Mole % Or	41.4	39.8	36.5	39.0	—	41.4	46.4	40.3	46.4	43.8		
Median Mole % Or	34.7	37.7	33.4	36.4	41.3	39.8	41.5	40.1	42.1	41.9		

Phenocryst-Groundmass Composition Comparisons: Comparison of the phenocryst and groundmass compositions from the same sample shows the minimum, maximum, and median differences to be 1.8, 15.3, and 7.6 mole % Or respectively. In all cases the groundmass composition is greater than the phenocryst composition from the same sample. These comparisons are shown in Table 7.

Table 7. Comparison of Phenocryst and Groundmass Compositions of the Same Sample.

<u>Sample No.</u>	<u>Pheno. Comp. Mole % Or</u>	<u>GM. Comp. Mole % Or</u>	<u>Difference Mole % Or</u>
II-1	36.8	40.3	3.5
IV-9	35.9	40.0	4.1
IV-11	32.9	40.4	7.5
VI-3	34.6	40.1	5.5
VI-11	32.9	42.5	9.6
VI-13	32.5	39.7	7.2
VI-15	32.2	46.4	14.2
VI-17	31.8	43.1	11.3
I-12	38.2	40.0	1.8
I-14	28.5	43.8	15.3
I-15	36.7	40.2	3.5

Structural State Analyses

The alkali feldspar structural state analyses⁽¹⁾ of this study were determined by x-ray diffraction using the 'three-peak' method as recommended by Wright and Stewart (1968) and Wright (1968). Simply stated, these techniques require measurement of the 2θ values for the $\bar{2}01$, 060 , and $\bar{2}04$ diffraction peaks which are empirically related to the "a", "b", and "c" cell parameters, respectively. The structural state of the feldspar is then estimated directly from a plot (see Figure 16) of 2θ (060) against 2θ ($\bar{2}04$) which was prepared from feldspars of known structural state (Wright, 1968, Figure 2, p. 91). A further refinement of this plot by Wright (1968, Figure 3, p. 92) allows estimation of the feldspar composition for those with normal cell dimensions (see Figures 17 and 18). Feldspars having anomalous cell dimensions⁽²⁾ may also be recognized on such a plot. Details of these techniques, as applied in this study, are discussed in Appendix 4.

Solid solutions resulting from exsolution of a homogeneous alkali feldspar into K- and Na-rich phases are common in the rocks of this study. The rocks rarely contain only a homogeneous phase or mixtures of homogeneous and exsolved K and Na solid solution phases. Examination of the diffractogram trace in the region of the $\bar{2}01$ peak allows easy differentiation of the number and types of alkali feldspar phases present (see Figure 19). Table 8

(1) By "structural state" in this work I mean the degree of ordering of Si and Al ions on the central sites of oxygen tetrahedra, and do not involve ordering of Na and K ions in the exsolution process in the term.

(2) Alkali feldspar cell dimensions are said to be anomalous if $^{\circ}2\theta$ ($\bar{2}01$) (measured) - $^{\circ}2\theta$ ($\bar{2}01$) (estimated) from Figure 17 is more than $0.1^{\circ} 2\theta$ (Wright, 1968, p. 93).

shows the ranges in 2θ for the K, Na, and homogeneous feldspar phases of this study and those reported by Wright (1968). It is possible to determine the composition of the unmixed phases if a unit cell refinement is made and the unit cell volume thus determined (Wright and Stewart, 1968, Figure 1), but this was not done for this thesis.

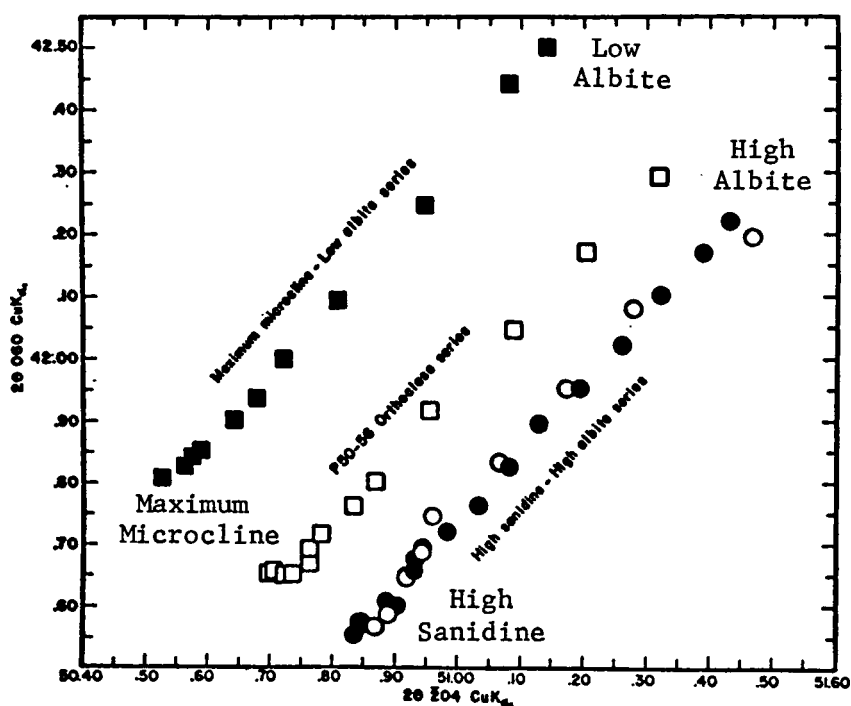


Figure 16. Observed 2θ values of 060 plotted against observed 2θ values of 204 for members of three complete series of alkali feldspars.

Solid Squares: Maximum microcline-low albite series, data of Orville (1967). Open Squares: P50-56F (orthoclase) series, data of Wright and Stewart (1968). Solid Circles: High sanidine-high albite series, data of Orville (1967). Open Circles: High sanidine-high albite series, data of Donnay and Donnay (1952) and written communication, 1963. Data points are drawn to $\pm 0.02^\circ 2\theta$ which exceeds the range observed in measurement of three x-ray patterns for each sample. After Wright (1968, Figure 2, p. 91).

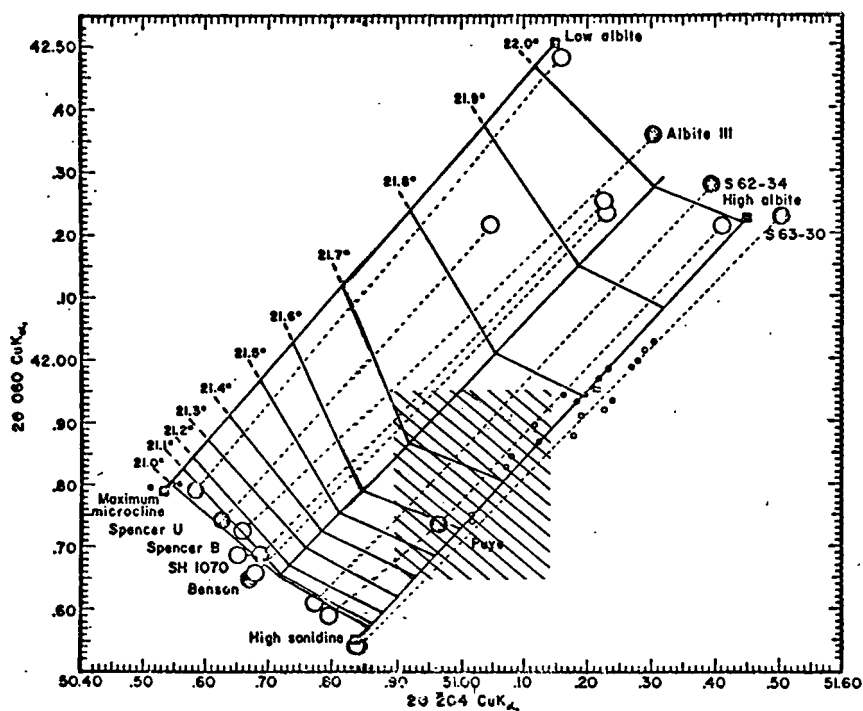


Figure 17. Alkali exchange paths on a plot of $2\theta\ (060)$ against $2\theta\ (204)$. The angular values on diagonal contours across the diagram are $2\theta\ (201)$ of phases of differing compositions and having normal (unstrained) cell dimensions. After Wright (1968, Figure 3, p. 92). The diagonal shaded portion of this figure is enlarged in Figure 20.

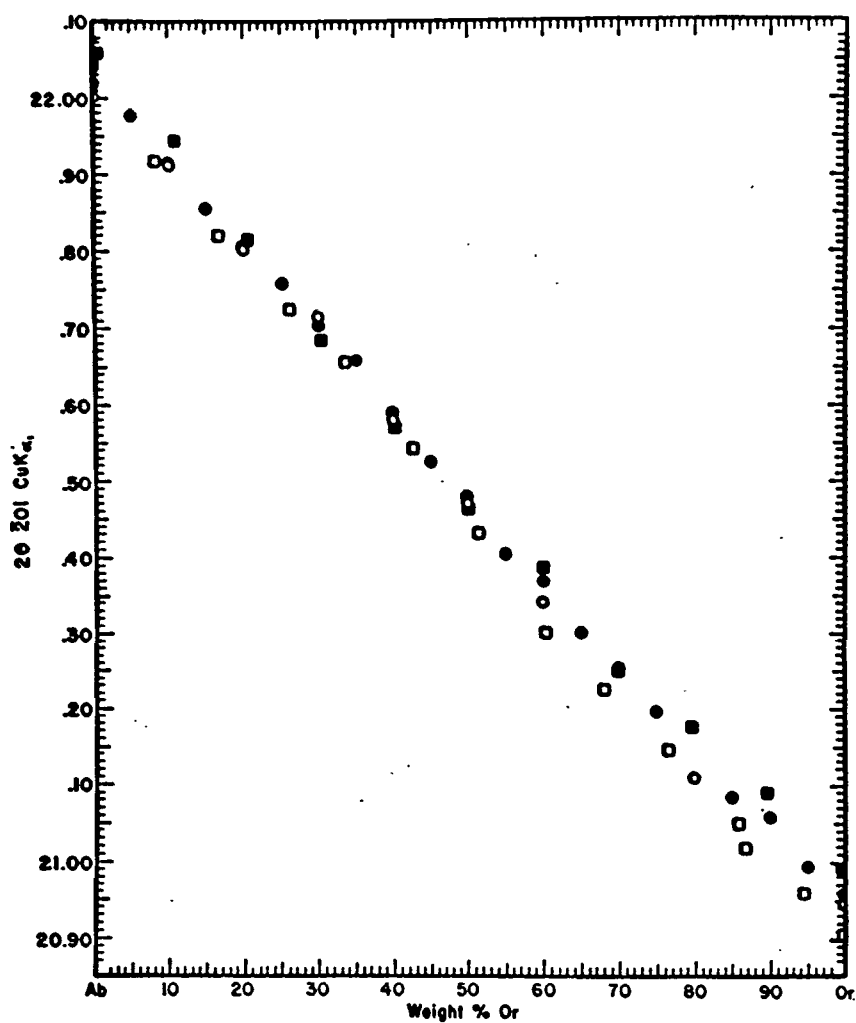


Figure 18. Or content plotted against 2θ ($\bar{2}01$) for three complete series of exchanged feldspars. Data sources as given for Figure 16. From Wright (1968, Figure 4, p.93)

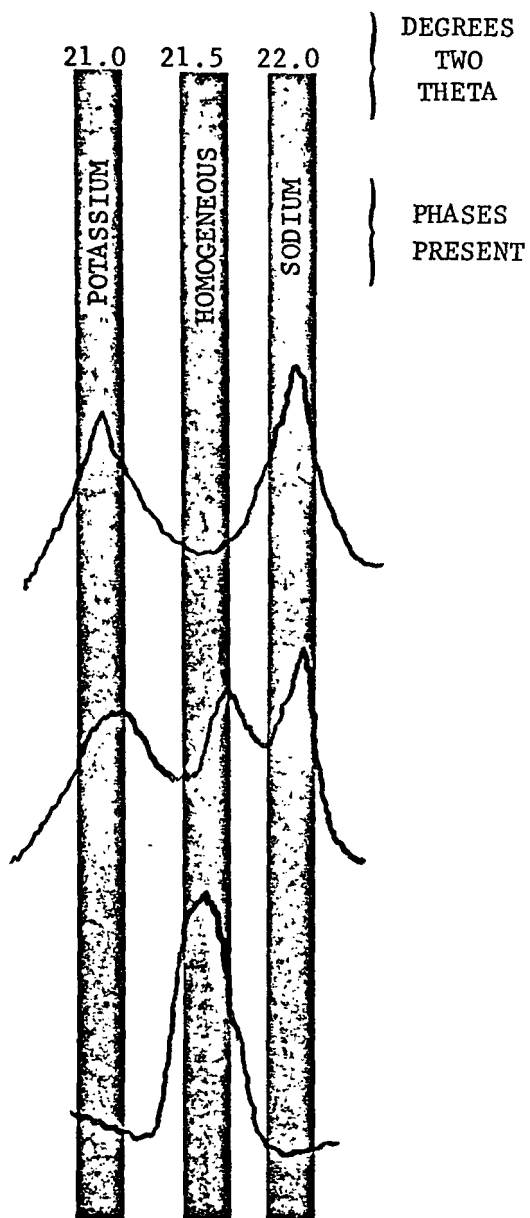


Figure 19. Representative diffractogram traces of the alkali feldspar phase combinations detected in this study based on the $\bar{2}01$ peak.

Table 8. Position of Alkali Feldspar
Reflections Used in the 'Three-Peak' Method

Miller Indices hkl	Range of 2 θ (CuK α)					
	For the Rocks of This Study			Approximate Range of Wright ⁽³⁾		
	<u>K-Rich Phases</u>	<u>Homogeneous Phases</u>	<u>Na-Rich Phases</u>	<u>K-Rich Phases</u>	<u>Anorthoclase</u>	<u>Albite</u>
$\bar{2}01$	20.87°-21.15°	21.52°-21.64°	21.95°-22.03°	20.8°-21.2°	21.6°-21.9°	21.9°-22.1°
060	41.69°-41.91°	——(1)	42.45°-42.50° ⁽²⁾	41.6°-42.0°	41.7°-42.0°	42.2°-42.6°
$\bar{2}04$	50.94°-51.09°	——(1)	——(1)	50.5°-51.1°	51.1°-51.3°	51.2°-51.5°

(1) Not detected.

(2) Detected only in groundmass samples.

(3) From Wright (1968, Table 1, page 89).

Each structural state analysis attempted in this study was graded according to its apparent quality. Thus acceptable structural state analyses have C, B, or A designations whereas unacceptable analyses have D or F designations for the $\bar{2}01$, 060, or $\bar{2}04$ diffraction peaks (see Appendix 7).

A total of 159 structural state analyses were attempted on 127 samples in this study. Of these, 42 (26 per cent) gave acceptable $\bar{2}01$ data for both the sodium and potassium phases; 154 (97 per cent) of the 060 and 139 (91 per cent) of the $\bar{2}04$ data were acceptable for the potassium phase.

The structural state analyses are enumerated in Table 9 (phenocryst samples) and Table 10 (groundmass samples). In these tables the samples are arranged in alphabetical, then numerical sequence. Duplicate analyses of a single sample are followed by an alphabetical designation. For each analysis the following data are presented:

- (a) Measured 2θ ($\bar{2}01$) for the potassium phase.
- (b) Measured 2θ ($\bar{2}01$) for the sodium phase.
- (c) Quality assessments of the $\bar{2}01$ potassium and sodium peaks.
- (d) Paper shrink and stretch correction in $^{\circ}2\theta$ as determined from the internal standard, (-) for stretch, (+) for shrink correction.
- (e) Indication of the presence and apparent amount of quartz as a check on the phenocrysts sample purity.
- (f) Calculated Δ ($\bar{2}01$) where Δ ($\bar{2}01$) = [$(^{\circ}2\theta$ ($\bar{2}01$) Na Phase) - $(^{\circ}2\theta$ ($\bar{2}01$) K phase)].
- (g) Measured 2θ (060) for the potassium phase.
- (h) Quality assessment of the 060 potassium peak.
- (i) Measured 2θ ($\bar{2}04$) for the potassium phase.
- (j) Quality assessment of the $\bar{2}04$ potassium peak.

TABLE 9: PHENOCRYST STRUCTURAL STATE ANALYSES

Sample Number	2 θ ($\bar{2}01$) K Phase	2 θ ($\bar{2}01$) Na Phase	Quality ⁽¹⁾ ($\bar{2}01$)		Paper ⁽²⁾ Correction ($^{\circ}2\theta$)		Quartz	$\Delta(\bar{2}01)$ ⁽³⁾	(4) Quality		2 θ ($\bar{2}04$) (4)	Quality ($\bar{2}04$)
			K	Na					2 θ (060)	(060)		
B-10	{ 21.127 21.67-	22.024	F	C	-.008	Weak	0.897-	HOMO.	41.796	C	50.986	D
B-15		22.019	F	C	-.018	Weak	1.069-		41.788	B	51.062	C
B-20		21.980	D	F	+.004	Strong	1.080-		41.770	B	51.006	C
Dam 3(A)	21.166	21.938	C	D	+.006	Weak	0.7716		41.808	C	51.026	D
Dam 3(B)	21.186	21.997	D	D	+.008	Weak	0.8110		41.806	C	51.008	B
Dam 3(C)	21.150	21.991	F	F	+.004	?	0.8405		41.835	D	51.008	C
C-1	21.141	21.944	D	C	-.004	Weak	0.8030		41.806	B	51.020	C
C-2	21.109	21.953	D	C	None	Weak	0.8430		41.831	B	51.028	A
C-4	21.113	21.965	D	B	None	Weak	0.8523		41.831	B	51.055	C
C-5	21.095	22.011	D	B	-.004	?	0.9153		41.870	B	51.032	B
C-6	21.095	21.978	D	C	+.010	Weak	0.8819		41.868	C	51.036	C
C-7	21.048	22.015	D	B	None	Weak	0.9665		41.857	C	51.040	B
C-9	21.013	21.979	D	C	-.012	Weak	0.9665		41.845	A	51.036	B
C-10	21.007	21.971	D	B	-.022	Weak	0.9645		41.861	B	51.020	C
C-11	20.999	21.975	C	A	-.008	Weak	0.9764		41.865	C	51.070	B
C-12(A)	21.030	22.010	D	B	None	Weak	0.9508		41.874	A	51.079	B
C-12(B)	21.034	21.995	D	B	+.009	Weak	0.9606		41.849	A	51.049	C
C-13(A)	20.870	22.010	C	B	-.004	Weak	1.1400		41.860	B	50.957	B
C-13(B)	21.040	21.950	C	A	-.030	Weak	0.9100		41.837	B	51.020	C
C-13(C)	21.010	21.975	D	B	-.008	Weak	0.9600		41.840	A	51.020	B
C-14	21.060	21.960	F	C	-.001	Weak	0.8996		41.847	B	50.990	A
C-15	21.070	21.965	D	B	+.008	Weak	0.8957		41.831	B	51.016	A
C-16	21.050	21.985	D	C	None	?	0.9310		41.830	B	51.014	B
C-17	21.066	21.937	C	C	+.009	Weak	0.8712		41.841	B	51.040	B

TABLE 9: PHENOCRYST STRUCTURAL STATE ANALYSES, CONTINUED

Sample Number	2 θ ($\bar{2}01$) K Phase	2 θ ($\bar{2}01$) Na Phase	Quality ⁽¹⁾ ($\bar{2}01$)		Paper (2) Correction ($^{\circ}2\theta$)		Quartz	Δ ($\bar{2}01$) ⁽³⁾	2 θ ($\bar{0}60$) ⁽⁴⁾	Quality ($\bar{0}60$)	2 θ ($\bar{2}04$) ⁽⁴⁾	Quality ($\bar{2}04$)
			K	Na								
C-19(A)	21.1--	21.977	F	D	+ .015	?	0.8---	41.800	A	51.008	C	
	21.7--			F	+ .015	?	HOMO.					
C-19(B)	21.35-	21.650	F	F	- .057	Weak	0.5---	41.750	A	50.977	A	
	21.9--			F	- .057	Weak	HOMO.					
C-19(C)	21.2--	21.631	F	F	- .026	Weak	0.67--	41.758	A	50.990	B	
	21.9--			D	- .026	Weak	HOMO.					
D-1(A)	21.616		A		- .014	Strong	HOMO	41.703	A	51.032	A	
D-1(B)	21.633		A		+ .002	?	HOMO	41.719	B	50.998	B	
D-1(C)	21.637		A		- .024	Weak	HOMO	41.723	B	50.996	B	
D-1(D)	21.611		A		- .002	Weak	HOMO	41.750	B	51.008	B	
D-1(E)	21.601		B		- .006	Strong	HOMO	41.748	A	50.988	C	
D-1(G)	21.619		A		- .014	Strong	HOMO	41.729	B	50.986	B	
D-2	20.924	21.702	F	C	- .059	Weak	0.7776	41.817	C	51.026	B	
D-4	21.127	21.999	D	C	- .030	?	0.8720	41.864	C	51.034	C	
D-5	21.081	21.977	C	B	+ .011	Weak	0.8957	41.860	B	51.075	C	
D-6	21.109	22.020	D	C	- .080	Weak	0.9114	41.823	A	51.032	C	
D-7	21.080	21.980	D	B	- .002	Weak	0.8976	41.890	B	51.043	B	
D-8	21.060	21.991	D	C	None	Weak	0.9311	41.864	C	51.067	C	
D-10	?	21.987	F	C	- .030	Weak	?	41.869	A	51.004	C	
D-14	21.066	21.983	D	C	- .049	Weak	0.9173	41.892	C	51.018	B	
D-17	20.962	21.987	B	C	- .024	?	1.0256	41.855	B	51.063	B	
D-20	21.082	22.017	D	B	- .024	Weak	0.9350	41.829	C	51.042	B	
D-22	21.015	21.983	F	C	- .028	Weak	0.9680	41.855	B	51.033	C	
D-24	20.960	21.946	F	F	- .012	Weak	0.9860	41.823	A	51.022	A	

TABLE 9: PHENOCRYST STRUCTURAL STATE ANALYSES, CONTINUED

Sample Number	2 θ ($\overline{201}$) K Phase	2 θ ($\overline{201}$) Na Phase	Quality ⁽¹⁾ ($\overline{201}$)		Paper ⁽²⁾ Correction ($^{\circ}2\theta$)	Quartz	$\Delta(\overline{201})$ ⁽³⁾	2 θ (060) ⁽⁴⁾	Quality (060)	2 θ ($\overline{204}$) ⁽⁴⁾	Quality ($\overline{204}$)
			K	Na							
E-2	21.019	21.967	C	B	None	Weak	0.9488	41.853	B	51.016	B
E-3	21.111	22.003	D	B	-.014	Weak	0.8917	41.827	A	51.038	B
E-4	21.050	21.963	D	C	-.030	?	0.9134	41.819	C	51.010	C
E-6	21.042	21.983	D	C	+.006	?	0.9409	41.843	C	51.086	B
E-8	21.050	22.013	D	A	-.024	?	0.9626	41.870	C	51.038	D
E-11	21.015	21.975	F	C	-.004	Strong	0.9606	41.900	A	51.063	D
E-12	21.007	22.009	F	C	-.014	Weak	1.0019	41.914	C	51.020	C
E-14(A)	21.006	21.993	F	C	-.014	Weak	0.9272	41.862	B	51.012	B
E-14(B)	21.001	22.969	C	D	-.004	?	0.9680	41.914	C	51.008	C
E-16	21.150	22.036	F	C	-.018	Weak	0.8858	41.886	B	51.030	C
E-17	20.983	21.977	D	C	-.036	Weak	0.9941	41.865	B	51.020	C
E-20	21.076	22.062	D	B	-.028	Weak	0.9409	41.806	B	51.018	B
E-24	21.060	21.991	F	F	-.020	Weak	0.9310	41.845	C	50.977	C
G-1	21.028	22.028	D	?	None	None	1.000	41.847	A	51.061	A
G-1/2	21.089	21.967	D	D	-.004	None	0.8779	41.833	A	51.061	A
G-3	21.046	21.997	D	D	-.002	None	0.9508	41.839	B	51.038	A
G-5	?	21.959	?	C	-.036	Strong	?	41.855	A	51.049	C
G-7	?	21.965	?	A	-.037	Strong	?	41.847	C	51.060	B
G-9	21.072	22.007	B	B	-.044	Weak	0.9350	41.825	B	51.022	C
G-11	21.042	21.996	D	A	None	None	0.9547	41.855	A	51.049	B
G-13	21.034	21.981	D	B	-.048	None	0.9468	41.902	B	51.038	B
G-15	21.013	21.938	C	D	-.028	None	0.9250	41.859	C	51.055	C
G-16	21.015	21.990	D	B	+.017	Weak	0.9763	41.880	B	51.057	C
G-18	21.040	21.970	F	B	-.018	None	0.9270	41.857	B	51.028	B
G-20	21.025	21.983	D	C	-.036	?	0.9586	41.837	B	51.028	D
G-20f	?	21.977	?	B	-.008	Strong	?	41.819	B	51.057	C

TABLE 9: PHENOCRYST STRUCTURAL STATE ANALYSES, CONTINUED

Sample Number	2 θ ($\overline{201}$) K Phase	2 θ ($\overline{201}$) Na Phase	Quality ⁽¹⁾ ($\overline{201}$)		Paper ⁽²⁾ Correction ($^{\circ}2\theta$)		Quartz	$\Delta(\overline{201})$ ⁽³⁾	2 θ (060) ⁽⁴⁾	Quality (060)	2 θ ($\overline{204}$) ⁽⁴⁾	Quality ($\overline{204}$)
			K	Na								
H-5	21.089	21.967	C	B	-.054		None	0.8779	41.809	B	51.014	C
H-7	21.103	21.967	F	C	+.004		None	0.8642	41.813	C	51.026	A
J-1	21.3--	21.922	F	D	-.032		?	0.6---	41.778	A	51.000	C
J-4	21.050	21.965	C	B	-.012		?	0.9134	41.857	B	51.044	B
J-6	21.032	21.993	D	C	+.006		None	0.9606	41.870	B	51.038	B
J-10	21.101	21.973	D	B	-.028		None	0.8720	41.823	A	51.045	C
K-1	21.097	21.975	C	C	-.008		None	0.8780	41.833	A	50.992	C
K-2	21.042	22.005	D	A	-.024		?	0.9626	41.835	B	51.028	C
K-3	20.989	21.975	C	C	-.010		?	0.9862	41.850	B	51.022	C
L-1(A)	21.050	21.960	F	C	+.035		?	0.9100	41.840	A	51.010	C
L-1(B)	21.050	21.970	D	C	+.010		?	0.9230	41.840	A	51.020	C
L-2	21.048	22.015	C	C	-.002		?	0.9665	41.886	A	51.047	C
L-3	21.014	22.003	D	C	-.026		?	0.9882	41.874	A	51.055	B
L-4(A)	21.056	21.971	D	B	-.026		None	0.9153	41.857	C	50.986	B
L-4(B)	21.021	21.985	F	C	-.036		None	0.9645	41.859	C	51.034	B
L-5	20.997	22.018	C	A	-.034		None	1.0216	41.821	B	50.998	C
L-7	21.064	22.026	C	A	-.028		?	0.9626	41.855	A	51.046	C
L-8	21.030	21.991	F	B	-.014		?	0.9606	41.870	B	51.030	B
L-9	21.036	21.973	B	B	-.024		None	0.9370	41.894	A	51.032	B
L-12	21.064	22.003	F	A	+.015		None	0.9390	41.874	B	51.028	B
L-13	20.985	21.987	F	B	None		None	1.0020	41.851	A	51.042	A
L-14	21.056	21.983	D	C	-.020		?	0.9272	41.837	A	51.055	B
L-15	21.064	22.013	C	C	-.006		None	0.9488	41.849	B	51.038	C
L-17	21.054	21.987	C	B	-.024		None	0.9331	41.823	A	51.036	B
L-18	21.080	21.889	D	F	-.006		Weak	0.8090	41.847	C	50.986	C

TABLE 9: PHENOCRYST STRUCTURAL STATE ANALYSES, CONTINUED

Sample Number	2 θ ($\overline{201}$) K Phase	2 θ ($\overline{201}$) Na Phase	Quality ⁽¹⁾ ($\overline{201}$)		Paper ⁽²⁾ Correction		Quartz	$\Delta(\overline{201})^{(3)}$	2 θ (060) ⁽⁴⁾	Quality (060)	2 θ ($\overline{204}$) ⁽⁴⁾	Quality ($\overline{204}$)
			K	Na	($^{\circ}2\theta$)							
I-4	21.57-		?		-.036	Weak	HOMO.	41.723	A	51.006	B	
I-10	21.3--	21.9	F	F	-.024	?	0.6---	41.799	A	50.970	C	
I-11	21.587		A		-.026	Weak	HOMO.	41.795	C	51.016	C	
I-12	21.146	21.965	C	B	-.020	None	0.8189	41.798	A	51.047	B	
I-14(A)	21.219	21.918	F	C	+.002	Weak	0.6988	41.790	C	51.032	C	
I-14(B)	21.221	21.959	F	F	-.016	?	0.7382	41.811	C	51.038	C	
I-14(C)	21.192	21.961	D	D	None	?	0.7697	41.788	B	51.016	C	
I-14(D)	21.209	21.957	D	D	-.014	Weak	0.7480	41.817	B	51.036	B	
I-15(A)	21.164	21.993	D	C	-.018	Weak	0.8287	41.839	C	51.057	C	
I-15(B)	21.141	21.965	F	D	-.014	Weak	0.8248	41.819	C	51.044	C	
I-15(C)	21.081	21.952	F	D	-.030	Weak	0.8701	41.800	B	51.030	C	
I-15(D)	21.280	21.894	F	F	-.016	None	0.6142	41.819	C	51.075	D	
I-16	21.212	21.938	D	D	-.032	None	0.7260	41.750	A	51.012	B	
II-1	21.3--	21.944	?	D	-.010	None	0.6---	41.782	B	51.052	C	
II-3	21.521		B		-.028	Weak	HOMO	41.699	B	50.945	B	
II-5	21.568		A		None	None	HOMO	41.721	B	50.982	D	
III-1	21.105	22.019	D	C	-.014	Weak	0.9134	41.829	C	51.038	C	
III-2	21.072	22.005	D	C	-.006	Weak	0.9331	41.825	A	51.051	C	
IV-1	20.963	21.967	F	C	-.004	Weak	1.0039	41.906	C	51.061	C	
IV-3	21.005	21.977	C	B	-.018	Weak	0.9724	41.849	C	51.055	B	
IV-5(A)	21.086	21.993	D	C	-.014	Weak	0.9075	41.870	C	51.036	C	
IV-5(B)	21.076	21.985	D	B	-.034	?	0.9094	41.835	C	51.020	C	
IV-5(C)	21.050	21.983	F	D	-.032	?	0.9331	41.882	C	51.036	C	
IV-7	21.2	21.9	F	F	-.030	None	0.7---	41.876	C	51.049	F	
IV-9	21.231	21.956	F	D	-.065	?	0.7244	41.802	B	51.014	C	
IV-11(A)	21.070	21.995	D	C	-.020	None	0.9252	41.868	B	50.961	C	
IV-11(B)	20.936	21.960	F	D	-.014	?	1.0236	41.882	C	50.998	C	
IV-11(C)	20.9--	21.991	?	C	-.002	?	1.-----	41.872	C	50.971	D	

TABLE 9: PHENOCRYST STRUCTURAL STATE ANALYSES, CONTINUED

Sample Number	2 θ ($\overline{201}$) K Phase	2 θ ($\overline{201}$) Na Phase	Quality ⁽¹⁾ ($\overline{201}$)		Paper ⁽²⁾ Correction ($^{\circ}2\theta$)	Quartz	$\Delta(\overline{201})$ ⁽³⁾	2 θ (060) ⁽⁴⁾	Quality (060)	2 θ ($\overline{204}$) ⁽⁴⁾	Quality ($\overline{204}$)
			K	Na							
V-7(A)	21.084	22.011	C	C	-.012	?	0.9272	41.874	B	51.010	C
V-7(B)	21.107	21.987	D	C	-.006	?	0.8799	41.841	B	51.006	A
V-7(C)	21.107	21.999	D	C	-.006	?	0.8917	41.868	C	50.975	C
V-7(D)	21.023	21.985	D	C	None	?	0.9626	41.890	B	51.008	B
V-5	21.595		C		-.038	Strong	HOMO.	41.748	B	50.973	C
VI-1	21.129	21.969	D	D	-.022	Weak	0.8405	41.823	C	51.044	C
VI-3	21.186	21.940	D	D	-.028	?	0.7539	41.776	A	51.016	C
VI-5	21.125	21.971	F	F	-.024	None	0.8464	41.865	D	51.044	C
VI-7	20.999	21.975	D	C	-.026	Weak	0.9764	41.857	C	51.053	D
VI-9	21.046	21.975	D	C	-.016	Weak	0.9291	41.872	B	51.055	C
VI-11	20.656	21.558	D	C	-.055	?	0.9016	41.823	B	51.004	C
VI-13	21.072	21.977	C	B	-.020	None	0.9055	41.849	B	51.049	D
VI-15	21.030	22.005	D	C	-.059	None	0.9744	41.831	A	51.004	C
VI-17	21.009	21.987	D	C	-.036	None	0.9783	41.843	A	51.049	C
VI-19(A)	21.009	21.983	C	C	+.009	?	0.9744	41.886	C	51.020	C
VI-19(B)	21.023	21.999	C	B	-.004	?	0.9764	41.868	B	51.016	C
VI-19(C)	21.028	22.007	C	C	-.004	?	0.9783	41.882	C	50.994	C
VI-19(D)	21.042	22.013	D	B	-.020	?	0.9705	41.888	B	51.036	C
VI-21	21.025	22.001	D	B	-.071	None	0.9764	41.794	C	51.020	B
VI-23(A)	21.086	21.993	D	B	None	None	0.9075	41.843	A	51.053	C
VI-23(B)	21.025	21.977	F	C	+.023	None	0.9527	41.910	B	51.055	C
VI-23(C)	21.066	22.001	D	A	+.009	None	0.9350	41.865	B	51.040	C
VI-23(D)	21.056	22.021	F	D	-.059	?	0.9646	41.837	C	50.986	D
VI-24	21.056	21.958	C	C	-.059	None	0.9016	41.823	C	51.055	C

(1) Criteria for assessment of peak quality may be found in Appendix 7.

(2) Correction for paper shrinkage and stretch in $^{\circ}2\theta$.

(3) $\Delta(201) = ((^{\circ}2\theta(201) \text{ Na Phase}) - (^{\circ}2\theta(201) \text{ K Phase}))$

(4) For K phase only; Na phase seldom discernable, and never better than "D" quality.

TABLE 10: GROUNDMASS STRUCTURAL STATE ANALYSES

Sample Number	2θ(201) K Phase	2θ (201) Na Phase	Quality ⁽¹⁾ (201)		Paper ⁽²⁾ Correction (°2θ)		2θ(060) K Phase	2θ(060) Na Phase	Quality (060)		2θ(204) ⁽⁴⁾	Quality 204
			K	Na	Δ(201) ⁽³⁾	K			Na			
I-14	20.865	21.963	A	C	None	1.098	41.776	42.492	B	D	50.982	C
I-15	20.893	21.993	A	C	-.010	1.100	41.802	42.508	C	D	50.998	D
II-1	20.877	21.993	B	C	-.010	1.116	41.798	42.449	B	C	50.992	D
IV-3	20.902	22.005	A	C	-.002	1.103	41.808	42.495	D	C	50.984	D
IV-9	20.904	22.015	C	F	-.034	1.111	41.817	42.528	D	F	50.953	D
IV-11	20.889	22.005	A	C	-.002	1.116	41.829	42.506	C	F	50.981	D
VI-3	20.887	21.967	D	C	-.002	1.082	41.790	42.461	A	F	51.008	C
VI-11	20.849	21.995	B	A	-.028	1.146	41.788	42.496	B	C	50.992	C
VI-13	20.855	22.013	A	B	-.002	1.158	41.837	42.443	C	F	50.979	D
VI-15	20.902	21.997	A	D	+.004	1.095	41.817	42.471	C	D	50.955	C
VI-17	20.857	21.995	A	B	-.016	1.138	41.837	42.487	C	F	51.004	D

(1) Criteria for assessment of peak quality may be found in Appendix 7.

(2) Correction for paper shrinkage and stretch in $^{\circ}2\theta$.

(3) $\Delta 201 = (^{\circ}2\theta \bar{2}01 \text{ Na Phase}) - (^{\circ}2\theta \bar{2}01 \text{ K phase})$

(4) For K Phase only.

Quartz was present in all groundmass samples, therefore its presence is not marked in Table 10. In addition, the groundmass samples produced measurable 2θ (060) for the sodium phase which are recorded in Table 10.

2θ ($\bar{2}04$) Against 2θ (060) Plot

Phenocryst Samples: All phenocryst samples analyzed which gave acceptable data are plotted on Figure 20 which is an enlarged portion of Wright's diagram (see Figure 17). Most samples plot in a loose cluster centered around $2\theta(060) = 41.84^\circ$ and $2\theta(\bar{2}04) = 51.03^\circ$. Tables 11 and 12 are summary tabulations of data from Table 9 and the distribution of the samples in Figure 20. Examination of these data show that the phenocryst samples may be subdivided into three groups:

Two Phase Samples: All samples shown with an open circle are unmixed, solid solutions of K and Na alkali feldspar phases which have anomalous cell dimensions. The K phase has an 'apparent' structural state of low sanidine. Only the K phase of these samples is plotted as the Na phase falls well above this portion of Wright's diagram.

Samples shown with a solid circle B-15, I-16, and II-1 are also unmixed solid solutions of K and Na alkali feldspar phases which have anomalous cell dimensions. The K phases have lower values of $\bar{2}01$ (apparently more K-rich) and their average 'apparent' structural state is higher (i.e. high sanidine) than that of those plotted as open circles. The slight shift toward high sanidine of this group from the previous group may simply be the result of the smaller number of samples.

Three Phase Samples: Samples shown with an open square (B-10 and C-19) contain both unmixed solid solutions of K and Na phases as well as a homogeneous alkali feldspar phase. In these samples the homogeneous

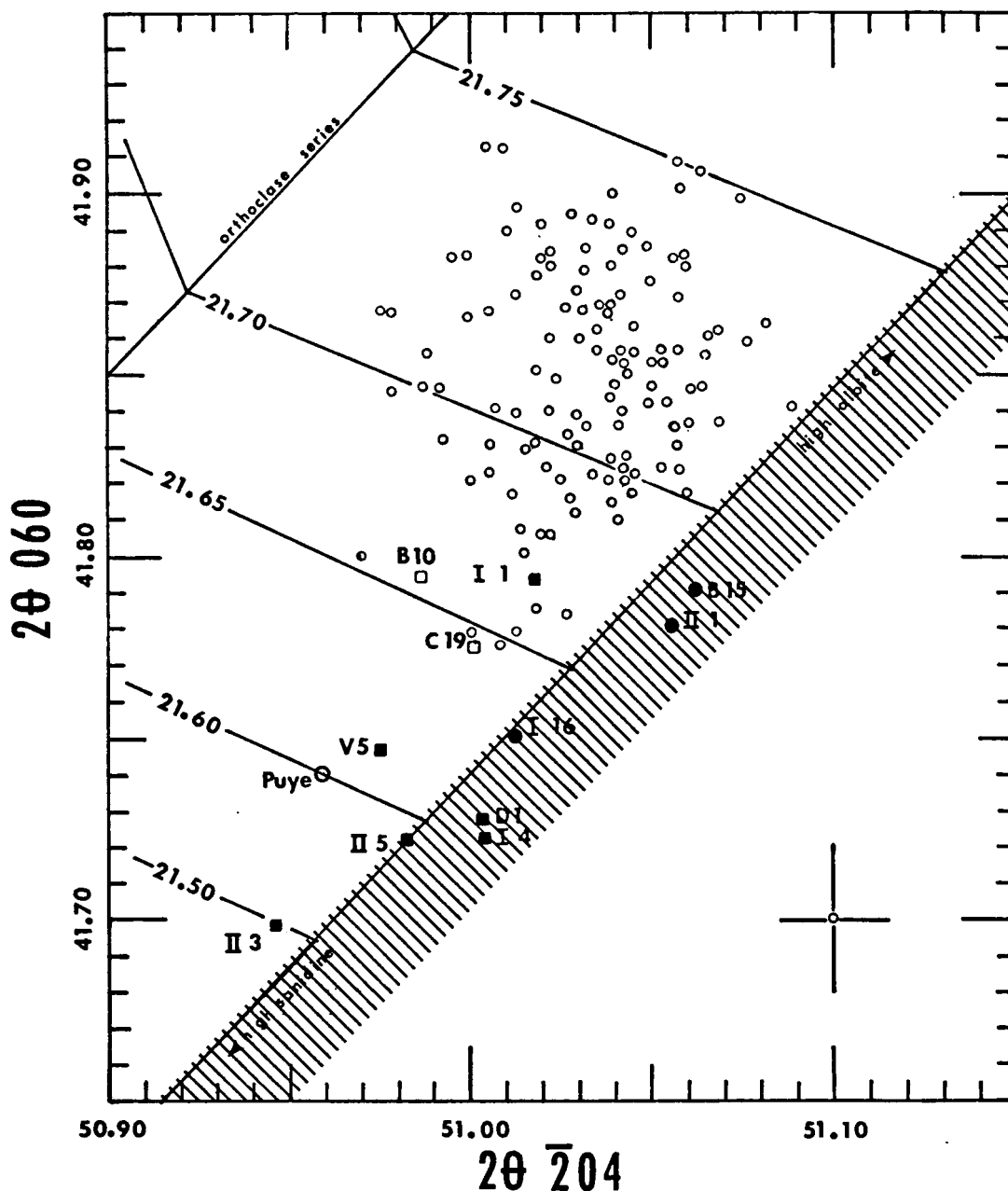


Figure 20. A plot of $2\theta(060)$ against $2\theta(\bar{2}04)$ for all phenocryst samples analyzed in this study (data from Table 9). The cross in the lower right shows a data point + and - one average standard deviation.

- Key:
- Samples which are solid solutions of K and Na phases with anomalous cell dimensions (only the K phase is shown on the plot).
 - Samples which are solid solutions of K and Na phases and which have anomalous cell dimensions but they have unusually high 'apparent' structural states (only the K phase is plotted).
 - Samples which contain both K and Na solid solution and homogeneous phases. The solid solution phases have anomalous cell dimensions (only the K phase is plotted). The homogeneous phase of these samples have normal cell dimensions and low sanidine structural states.
 - Samples which contain only a homogeneous phase with normal cell dimensions. Structural states range from low to high sanidine.

The diagonal shaded area designates the high sanidine field. The unshaded portion from the high sanidine field to the orthoclase series is the low sanidine field as the terms are applied in this study. This simplified subdivision is not as recommended by Wright and Stewart (1968) but is justified in expectation of future unit cell refinement data.

Table 11. Summation of
Data from Figure 20 and Table 9

Phenocryst			
<u>Sample</u>	<u>Phases Present</u>	<u>Structural State</u>	<u>Cell Dimension</u>
B-10	K, Na, and Homogeneous	Low Sanidine	Normal (Homogeneous Phase)
B-15	K and Na Only	High Sanidine	Anomalous
C-19	K, Na, and Homogeneous	Low Sanidine	Normal (Homogeneous Phase)
D-1	Homogeneous Only	High Sanidine	Normal
I-4	Homogeneous Only	High Sanidine	Normal
I-11	Homogeneous Only	Low Sanidine	Normal
I-16	K and Na Only	High Sanidine	Anomalous
II-1	K and Na Only	High Sanidine	Anomalous
II-3	Homogeneous Only	Low Sanidine	Normal
II-5	Homogeneous Only	Low Sanidine	Normal
V-5	Homogeneous Only	Low Sanidine	Normal
All Others	K and Na Only	Low Sanidine	Anomalous
Groundmass			
All Samples	K and Na Only	Low Sanidine	Anomalous

Table 12. Summation of Structural State Data
for All Samples With a Homogeneous Phase

<u>Sample</u>	<u>No. of Analyses</u>	<u>$^{\circ}2\theta$ ($\bar{2}01$) Homogeneous Phase</u>	<u>$^{\circ}2\theta$ ($\bar{2}01$) Predicted⁽¹⁾</u>	<u>Measured -Predicted $^{\circ}2\theta$ ($\bar{2}01$)</u>	<u>Cell Dimensions</u>	<u>Other Phases Present</u>	<u>Sample Location</u>
B-10	1	21.67-	21.660	0.01-	Normal	K & Na	South Prong
C-19	3	21.660 ⁽²⁾	21.645 ⁽²⁾	0.015	Normal	K & Na	Main Mass Periphery
D-1	6	21.621 ⁽²⁾	21.610 ⁽²⁾	0.011	Normal	None	Main Mass Periphery
I-4	1	21.57-	21.60-	0.03-	Normal	None	Dike
I-11	1	21.587	21.680	0.093	Normal	None	South Prong
II-3	1	21.521	21.495	0.026	Normal	None	Dike
II-5	1	21.568	21.590	0.022	Normal	None	Dike
V-5	1	21.595	21.615	0.020	Normal	None	North Prong

(1) From 2θ contours on Figures 17 and 20.

(2) Average of all analyses.

phase has normal cell dimensions and a low sanidine structural state.

Homogeneous Samples: Samples shown with a solid square (D-1, I-4, I-11, II-3, II-5, and V-5) contain only a homogeneous alkali feldspar phase. Of these, I-4, II-5, and D-1 are high sanidine, whereas the balance are low sanidine.

Summary: Table 12 shows that all samples with a homogeneous alkali feldspar phase have normal cell dimensions for that phase. No other samples of this study other than those listed in Table 12 have normal cell dimensions. Note that these samples are either from dikes, the prongs, or from the main mass periphery; no main mass core samples have homogeneous phases.

Table 13 shows a comparison of alkali feldspar compositions (using Figures 18 and 20) determined by the 'three peak method' with composition determined by the Orville or Tuttle and Bowen method (using Table 4). The 'three peak method' gives compositions of 1.7 to 5.0 (average 3.1) mole % Or lower than the Orville or Tuttle and Bowen method. The reasons for this disparity are not readily apparent.

Groundmass Samples: All groundmass samples (not shown on Figure 20) would plot in a cluster centered around $2\theta(060) = 41.81^\circ$ and $2\theta(\bar{2}04) = 50.98^\circ$. They all contain only K and Na solid solution phases (no homogeneous phases) and all have anomalous cell dimensions with an 'apparent' low sanidine structural state. This displacement toward a K-rich composition is not surprising in light of the overall potassium richness of the groundmass (Table 5), but without unit cell volume determination the true composition of these K-phases is not known.

TABLE 13

Comparison of Natural Homogeneous Alkali Feldspar Composition Determined by the 'Three Peak Method' With Compositions Determined by the Orville or Tuttle and Bowen Method.

Sample	'Three Peak Method'		Orville or Tuttle (1) and Bowen Method		Difference
	Wt. %	Mole %	Mole %		Mole %
B-10	34.5	33.2	35.3	O	2.1
C-19	35.9	34.6	36.7	O	2.1
D-1	37.7	36.3	38.4	O	2.1
I-4	39.0	37.6	39.3	TB	1.7
I-11	32.9	31.6	36.6	TB	5.0
II-3	46.6	40.5	40.5	TB	4.5
II-5	40.3	38.9	41.4	TB	2.5
V-5	37.7	36.3	41.3	O	5.0

(1) O denotes analyses using the Orville method, TB denotes analyses using the Tuttle and Bowen method.

$\Delta(\bar{201})$ Data

Phenocryst Samples: The $\Delta(\bar{201})$ values (a measure of the degree of unmixing between the K and Na phases from the homogeneous state) of the phenocryst samples (Table 9) varies from 0.6 to 1.14° 2 θ . Although the data are poor due to the low quality of the K-phase peaks, there is a definite trend from the more unmixed samples in the main mass core (with $\Delta(\bar{201}) > 0.85^\circ 2\theta$) to the less unmixed samples ($\Delta(\bar{201}) = 0.75^\circ$ to $0.85^\circ 2\theta$) near or at the main mass periphery or in the prongs. All homogeneous samples and slightly unmixed samples ($\Delta(\bar{201}) < 0.75^\circ 2\theta$) are from the main mass periphery, the prongs, or from dikes. Figure 21 shows the spatial distribution of the $\Delta(\bar{201})$ groups noted above.

Groundmass Samples: The $\bar{201}$ values of the groundmass samples range from 1.08 to 1.16° 2 θ . Thus the bulk of the groundmass samples are more unmixed than the bulk of the phenocrysts. Table 14 shows that the groundmass is invariably more unmixed than the phenocrysts with which they occur.

Table 14. Comparison of $\Delta(\bar{201})$ values for phenocryst and groundmass from the same sample.

Sample	$\Delta(\bar{201})$ Phenocryst	$\Delta(\bar{201})$ Groundmass
I-14	0.7412	1.098
I-15	0.7844	1.100
II-1	0.6---	1.116
IV-3	0.9724	1.103
IV-11	0.9829	1.116
VI-3	0.7539	1.095
VI-11	0.9016	1.082
VI-13	0.9055	1.142
VI-15	0.9744	1.158
VI-17	0.9783	1.138

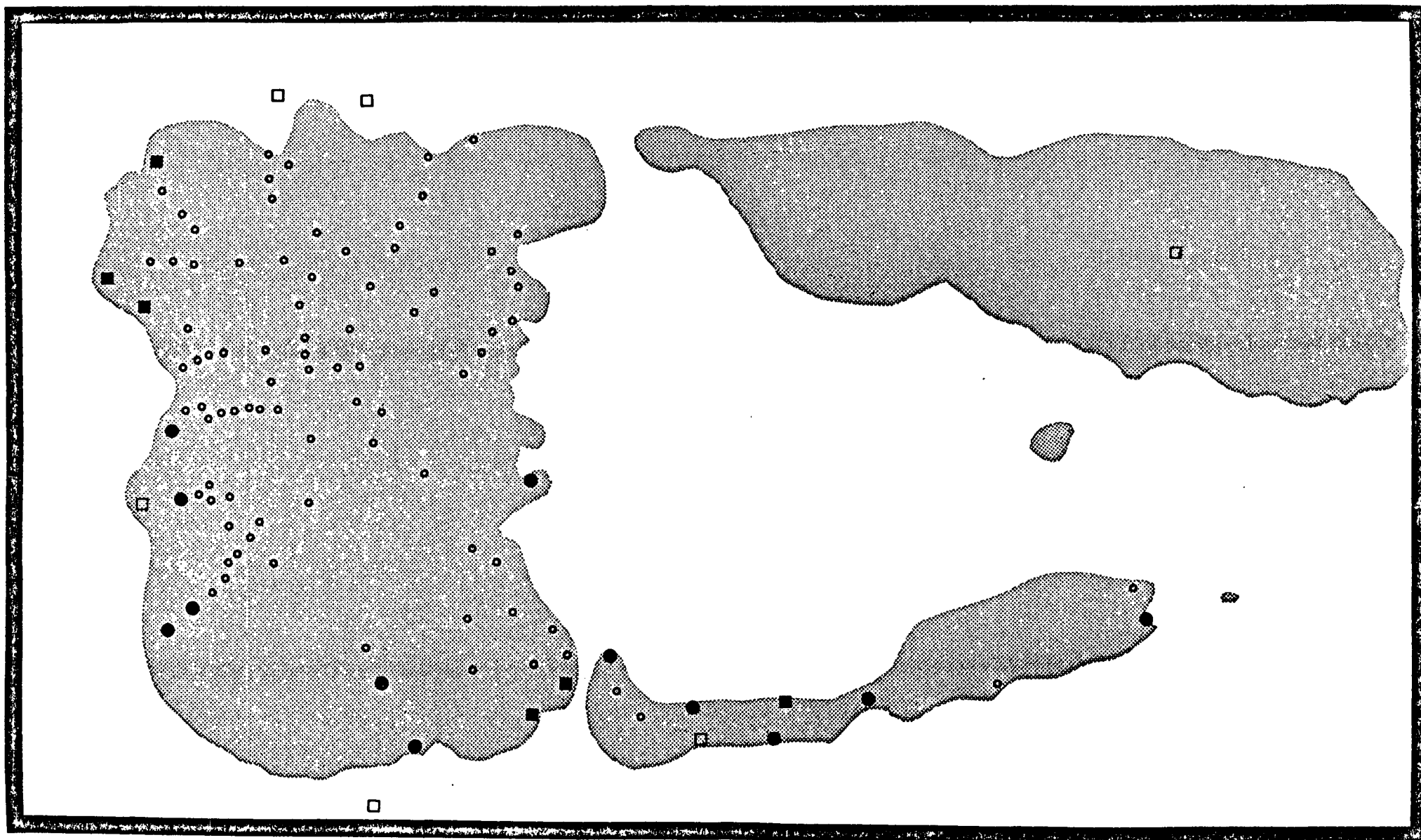


Figure 21. Spatial distribution of phenocryst Δ_{201} values.

Key:

- > 0.85
- = 0.75 to 0.85
- < 0.75
- = Homogeneous

Table 15. Summary of
Structural State Analyses

	Phenocryst					
	$^{\circ}2\theta$ ($\bar{2}01$) <u>K</u>	$^{\circ}2\theta$ ($\bar{2}01$) <u>Na</u>	$^{\circ}2\theta$ Homogeneous Phase	$\Delta \bar{2}01$	$^{\circ}2\theta$ (060) <u>K</u>	$^{\circ}2\theta$ $\bar{2}04$ <u>K</u>
Minimum	20.870	21.950	21.521	0.6---	41.699	50.945
Maximum	21.146	22.026	21.637	1.0256	41.910	51.086
Median	21.050	21.985	21.599	0.9346	41.830	51.029
Number of Analyses	139	139	15	139	147	147
No. Acceptable Analyses	29	107	10	29	145	135
% Acceptable	20.8	77.0	66.6	20.8	98.6	91.8

Table 15, Continued

	Groundmass					
	$\begin{array}{c} ^\circ 2\theta \\ (\bar{2}01) \\ \hline K \end{array}$	$\begin{array}{c} ^\circ 2\theta \\ (\bar{2}01) \\ \hline Na \end{array}$	$\Delta \bar{2}01$	$\begin{array}{c} ^\circ 2\theta \\ (060) \\ \hline K \end{array}$	$\begin{array}{c} ^\circ 2\theta \\ (060) \\ \hline Na \end{array}$	$\begin{array}{c} ^\circ 2\theta \\ (\bar{2}04) \\ \hline K \end{array}$
Minimum	20.904	21.963	1.095	41.837	42.449	50.955
Maximum	20.849	22.013	1.158	41.776	42.496	51.008
Median	20.879	21.992	1.119	41.807	42.480	50.983
Number of Analyses	11	11	11	11	11	11
No. Acceptable Analyses	10	10	9	9	3	4
% Acceptable	90.9	90.9	81.8	81.8	27.3	36.3

Summary of Structural State Analyses

Table 15 contains a tabulation of minimum, maximum, and median values for all structural state parameters measured and calculated on the phenocryst and groundmass samples of this study, as presented in Tables 9 and 10. In addition, the number of analyses attempted, the number of acceptable analyses, and the percentage of acceptable analyses are presented⁽¹⁾ for each of the parameters.

Microprobe Results

Dr. M. F. Carman has studied many alkali feldspar grains from this mass by electron microprobe analysis. Table 16 shows the microprobe analysis results of his sample MC-8:

Table 16. Microprobe Results

<u>Percentage</u>	<u>Phenocryst</u>		<u>Groundmass</u>	
	<u>Core</u>	<u>Rim</u>	<u>Core</u>	<u>Rim</u>
An	<1- 1	0	1	0
Or	37	44	35	46
Ab	62	56	64	54

Dr. Carman feels these data are typical of the results expected for the rocks of this intrusion, based on many similar analyses.

(1) Many samples were subjected to two or more analyses.

OTHER MINERAL PHASES

Pyroxene

A green pyroxene mineral (either sodic or ferro-augite, though an unequivocal determination was not possible) occurs as altered subhedral and anhedral phenocrysts up to 1.7 mm. across (see Figure 22). A complete grain size gradation is present, however, down to the minute (.01 mm.) subhedral and euhedral inclusions so common along the peripheries of alkali feldspar phenocrysts. The pyroxenes are present in amounts from 0.2 per cent to 10.6 per cent. Very low percentages reflect badly altered samples in which it was not possible to estimate the amount of pyroxene destroyed by alteration. The phenocrysts (> 0.3 mm.) never account for more than 1 per cent of any sample, and are often absent altogether. The phenocrysts are generally altered to various iron oxides but the rare fresh grains are non-pleochroic with bronze-brown cores and rims suggesting gradations to normal augite. $2V$ ranges from approximately 52° to 58° (three imprecise determinations were possible). Typical pyroxene cleavage is present in most grains.

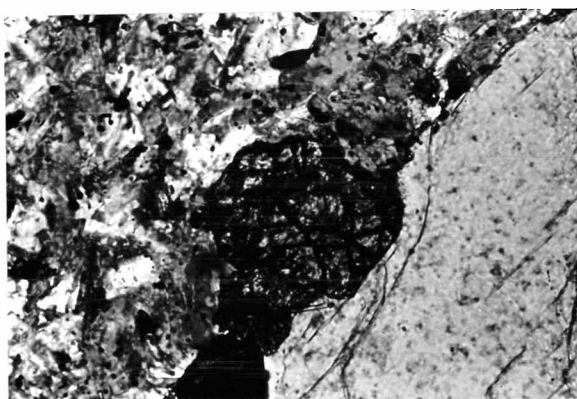


Figure 22. Thin section view at 30x under crossed nichols of pyroxene phenocryst.

Quartz

This ubiquitous species occurs as late interstitial, anhedral grains as much as 0.06 mm. across. The amount of quartz present in these rocks is not known with certainty. The relief and overall appearance of the quartz was so like that of the interstitial alkali feldspar material that no flat-stage optical differentiation was possible. U-stage examination allowed relatively easy differentiation of the two species, but no point count could be effected on that device. Thus an x-ray diffraction technique for the quantitative estimation of the amount of quartz was developed (Appendix 7) specifically for this determination. The x-ray results do not, unfortunately, agree with the amount of normative quartz calculated. The discrepancy may reflect the fact that non-normative mineralogical combinations are present in these rocks (such as the pyroxene) or to some basic flaw in the x-ray technique. The normative calculations give from 15 to 21 per cent quartz, whereas the x-ray technique indicates 0.9 to 6.2 per cent quartz is present. Future work on these rocks may resolve this problem.

Zircon

Zircon occurs as late interstitial anhedral and rare euhedral grains in sizes ranging from .05 mm. to .01 mm. There appears to be an intimate relationship between the late interstitial zircon and green pyroxene, as they often occur together. The mineral is present in amounts less than 1 per cent, and none was noted in samples from the prongs.

Iron Oxides

Opaque iron oxides form 1 to 10 per cent of the minerals in the rocks of this mass. The relative proportion of primary versus secondary species and specific delineation of these minerals would require a detailed

metallographic investigation; such an investigation was not attempted in this work. cursory examination proved the primary minerals to be predominantly magnetite and the secondary minerals predominantly limonite. The primary iron oxides range from $< .005$ mm. to $.09$ mm.; generally they range from anhedral to euhedral as grain size decreases. The secondary minerals often pseudomorph the sodic pyroxene.

Plagioclase

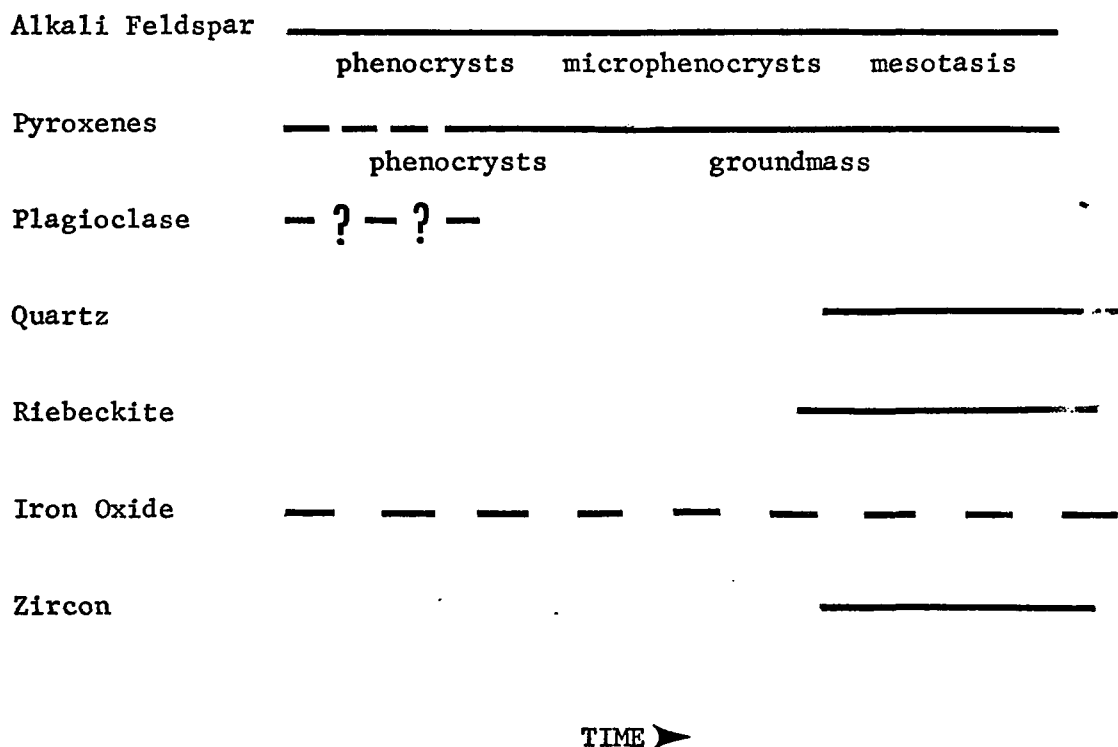
Three grains of plagioclase were noted in the examination of these rocks. The plagioclase occurs as individual albite-twinned, anhedral grains up to 0.5 mm. across, oriented in such ways that no composition determinations were possible by optical means. These grains may be either a primary crystallization constituent of this magma, or xenolithic inclusions (this problem is discussed later); no criteria are present for exact assessment of their origin.

Riebeckite

Rare, fine-grained (up to $.08$ mm.), anhedral grains of a light blue, pleochroic mineral are tentatively identified as riebeckite. These grains occur as late interstitial growths intimately associated with green pyroxenes in the groundmass of samples in the center and on the north face of the main mass.

Sequence of Crystallization Based on Textures

The textural relationships noted in the examination of over 200 thin sections indicate the following sequence of crystallization:



These relationships are based on the following observations:

- (1) Small pyroxene phenocrysts are included in feldspar phenocrysts.
- (2) Iron oxide inclusions occur in both feldspar and pyroxene phenocrysts and in the groundmass and as intergranular accumulations.
- (3) Zircon, quartz, and riebeckite occur as anhedral, interstitial grains.
- (4) Riebeckite is intimately intergrown with pyroxene in the groundmass.
- (5) Minute inclusions of pyroxene are common in the outer mantle of alkali feldspar phenocrysts.

BULK CHEMISTRY

Based on the average of the analyses that are available (Table 17) and the normative mineralogy derived therefrom (Table 18), the rocks of this mass are alkalic ($\text{Na}_2\text{O} + \text{K}_2\text{O} > \text{CaO}$), subaluminous ($\text{Al} > \text{Na} + \text{K}$) and distinctly oversaturated with respect to silica. Considering the spatial distribution of the analyzed samples (MC-7 near the center of the mass, MC-15 near the southern periphery) there may be possible trends in the data; but until more analyses are available for comparison, such trends are uncertain.

The disparity between the amount of normative quartz and the x-ray diffraction-determined quartz may well reflect some basic deficiency in the x-ray method employed, although no obvious weaknesses are apparent. The difficulty inherent in the quantitative estimation of fine-grained quartz may explain why many researchers often make no attempt at complete modal analyses.

Figure 23 shows the normative distribution of Ab, Or, and Q of these rocks as compared to the granites (or rhyolites) of Tuttle and Bowen, 1958. Note that the normative composition is just below the granite (or rhyolite) field of Tuttle and Bowen (triangle abc). A small increase in the amount of quartz would place the rocks of this mass in the Tuttle and Bowen, as well as the Streckeisen, granite (or rhyolite) fields.

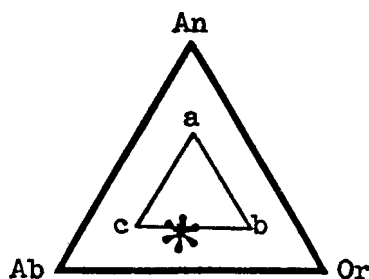


Figure 23. The normative distribution of Ab, Or, and Q of these rocks as compared to the granites (or rhyolites) of Tuttle and Bowen (1958, p. 128).

	Samples			Average ⁽³⁾
	MC-7		MC-15	
	(1)	(2)	(1)	
SiO ₂	67.20	68.24	69.58	68.39
TiO ₂	0.29	0.346	0.26	0.27
Al ₂ O ₃	14.84	14.52	14.22	14.53
Fe ₂ O ₃	3.34	3.803	2.79	3.06
FeO	0.66		0.67	0.66
MnO	0.16	0.175	0.03	0.09
MgO	0.16	0.04	0.43	0.29
CaO	1.80	1.190	1.45	1.62
Na ₂ O	5.16	5.490	4.59	4.87
K ₂ O	5.20	5.996	5.09	5.14
H ₂ O	0.52	0.000	0.78	0.65
H ₂ O+	0.34		0.23	0.28
P ₂ O ₅	0.06	0.200	0.05	0.05
CO ₂	0.15		0.18	0.16
S	0.12		0.03	0.07
Total	100.03	99.999	100.38	100.13

Based on the data above:

(1) Oxides recalculated to 100 per cent

[K ₂ O	42.8	45.7	44.2]
[Na ₂ O	42.4	41.2	41.8]
[CaO	14.8	13.0	13.9]
[Fe ₂ O ₃ + FeO	27.5	25.5	26.5]
[MgO	1.1	3.2	2.1]
[Na ₂ O + K ₂ O	71.3	71.3	71.3]

(2) Elemental concentrations recalculated to 100 per cent

[K	45.8	41.9	43.8]
[Na	40.6	37.8	39.2]
[Ca	13.5	10.2	11.8]
[Fe ^(+2,+3)	25.6	21.0	23.3]
[Mg	0.9	2.2	1.5]
[Na + K	73.4	76.8	75.1]

(1) Wet Chemical Analyses by M. Chiba

(2) X-Ray Fluorescence Analysis by B. Gunn

(3) Average of the MC-15 and MC-7 analyses by M. Chiba;
all data in weight per cent.

Table 18. Normative Analyses

	Sample		Average
	MC 7	MC 15	
Quartz (Q)	14.94	20.58	17.76
Orthoclase (Or)	30.58	30.02	30.30
Albite (Ab)	43.49	38.77	41.13
Anorthite (An)	1.95	3.06	2.50
Wollastonite (Wo)	2.44	0.46	1.45
Diopside (Di)	1.73	2.37	2.05
Hematite (He)	2.56	1.76	2.16
Magnetite (Mg)	1.16	1.39	1.27
Ilmenite (Il)	0.61	0.46	0.53
Pyrite (Py)	0.24	Trace	0.12
Apatite (Ap)			
Total	99.70	98.87	99.27

Based on the data above:

- (1) Total percentage of various groups of minerals after recalculating total norm to 100%.

(Q + Or + Ab + An)	91.23	93.49	92.36
(Q + Or + Ab)	89.28	90.39	89.83
(Or + Ab + An)	76.25	72.67	74.46
(Or + Ab)	74.29	69.58	71.93

- (2) Various mineral groups recalculated to 100 per cent:

Q	16.6	22.3	19.4
Or	33.6	32.5	33.0
Ab	47.8	41.9	44.8
An	2.1	3.3	2.7
Q	14.9	23.0	18.9
Or	34.3	33.6	34.0
Ab	48.8	43.4	46.1
Or	40.2	41.7	40.9
Ab	57.2	53.9	55.5
An	2.6	4.3	3.5
Or	41.2	43.6	42.4
Ab	58.7	56.4	57.5

PHASE RELATIONSHIPS

Phase Studies to Date

1. The System Ab-Or-An. Discussion of the crystallization sequence of the minerals studied best begins in the system Ab-Or-An ($\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - $\text{CaAl}_2\text{Si}_2\text{O}_8$). More than 70 per cent of the constituents of these rocks can be represented in this ternary system. The general relationships in the system are shown schematically in Figure 24, and concisely explained by I. S. E. Carmichael (1963, p. 98) in the following paragraph:

"The liquidus surface (parallel lines) dips down from the melting temperatures of An, Ab, and Or to intersect the field boundary EF which separates the plagioclase field from the alkali feldspar field. The solidus (stippled) intersects the liquidus at four points; the melting temperatures of An, Ab, Or, and the minimum melting composition in the alkali feldspar system (M). The top of the dome-shaped solvus intersects the solidus along HP'PAA'GE. The solvus is truncated by a vertical plane along the alkali feldspar solvus (C-D). The field boundary intersects the solvus dome only at E and thereafter, with falling temperature, runs towards the alkali feldspar minimum (M), which it does not reach, fading out just before at F. This field boundary represents the compositions of liquids in equilibrium with two feldspars. Two hypothetical three-phase triangles are shown L'P'A' and LPA where L represents the composition of the liquid, P the plagioclase and A the alkali feldspar."

Figure 25⁽¹⁾ shows the relationships of Figure 24 projected to the base of the prism (i.e. temperature considerations eliminated). Thus the line EF (termed a boundary curve) represents the composition of liquids in equilibrium

(1) In the diagrams which follow, the composition of the soda microsyenite of this study is shown with an asterisk. The composition shown in this manner is the normative mineralogical composition based on the analyses of Samples MC7 and MC15 (Table 18) recalculated to 100 per cent for the combination of normative constituents portrayed in a given diagram. In these discussions it is assumed that these samples closely approximate the composition of the initial, pre-crystallization liquid.

with a plagioclase and alkali feldspar having compositions along the PK_sA curve. The point K_s represents the composition of a single feldspar in equilibrium with a liquid of composition F . Point M represents the binary alkali feldspar minimum. This particular diagram is accurate only for conditions expected in the crystallization of a trachytic magma (Tuttle and Bowen, 1958, p. 132). The probable effect of composition on the extent of solid solution in this system is shown in Figure 26 (Tuttle and Bowen, 1958, Figure 66, p. 135) in which the positions of the curves are controlled by the solution of water, silica, and nepheline in liquids of composition Ab-Or-An.

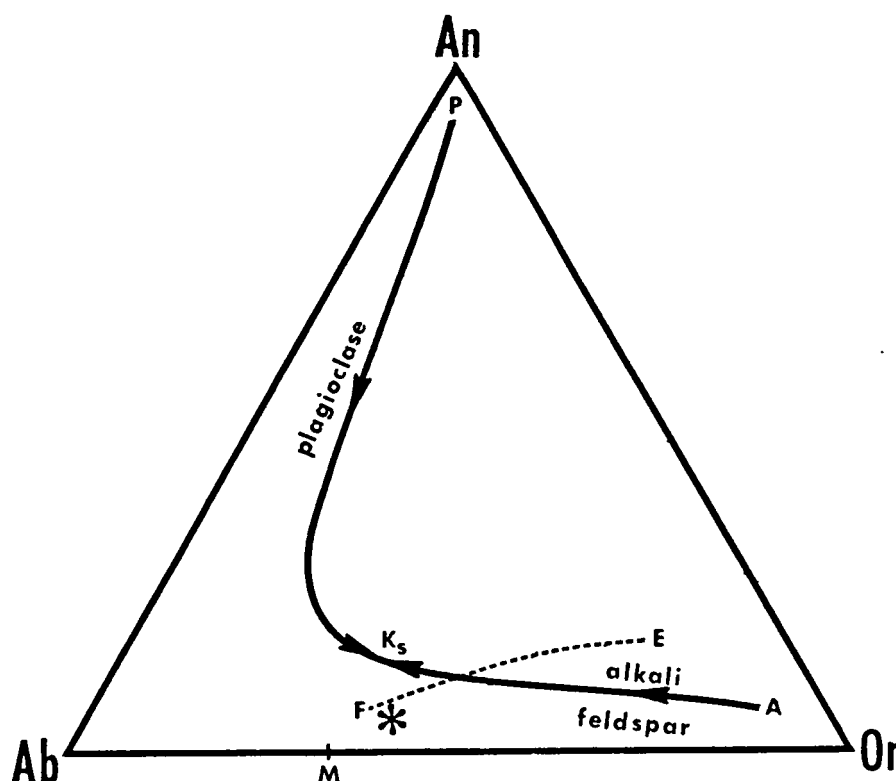


Figure 25. Ternary diagram of the system Ab-Or-An. The approximate limit of solid solution under conditions expected in trachytic magmas is given by the curve PK_sA . Feldspars having compositions along PK_sA are in equilibrium with liquids having compositions along EF . The arrows indicate the direction of falling temperature. After Rahman and MacKenzie (1969, Figure 2, p. 399).

The solution of water in such liquids is largely controlled by the external pressures to which the liquids are subjected. Each curve represents the line of intersection between the solvus and the solidus and points on the curves represent the composition of two feldspars in equilibrium with a

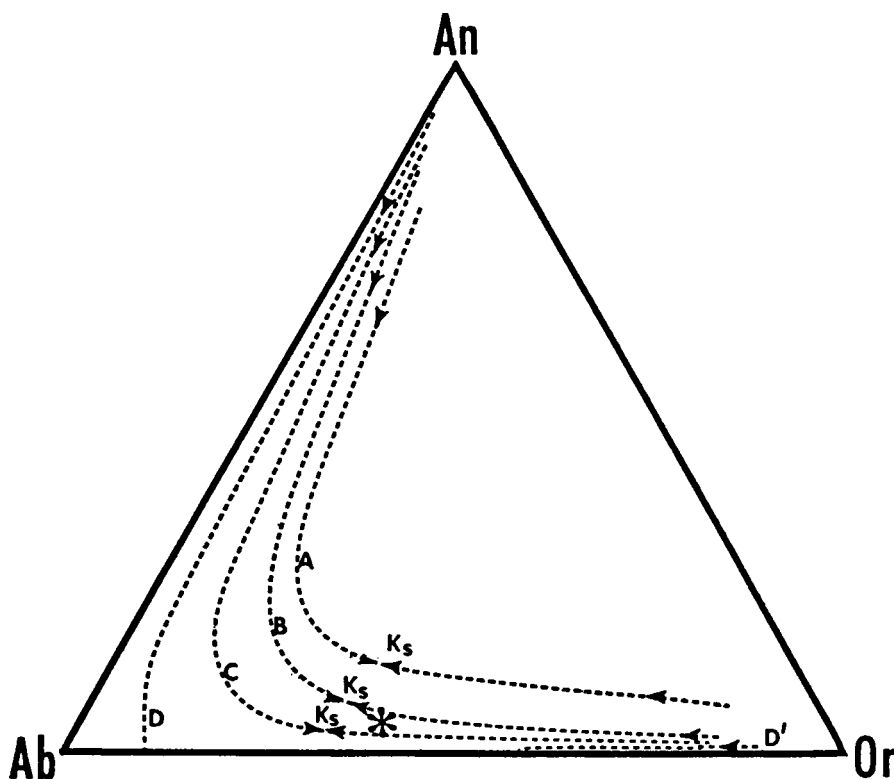


Figure 26. Ternary diagram illustrating the probable extent of solid solution in the system Ab-Or-An at four different temperature ranges. After Tuttle and Bowen (1958, Figure 66, p. 135).

liquid where:

curve A represents dry, high temperature conditions, such as in dry trachytic magmas;

curve B lower temperature, such as in dry rhyolites or possibly wet trachytes;

curve C a still lower temperature such as in rhyolites and phonolites with high water content;

and curve D-D' at temperatures so low that two feldspars can coexist in equilibrium with liquid when no An is present as in rhyolites and phonolites with very high water content.

Point K_s on curves A, B, and C represents the composition of a single alkali feldspar in equilibrium with a liquid located toward the Or corner (e.g. on line EF in Figure 25) and it is also a thermal minimum for solid phases along the solvus-solidus line of intersection. The soda microsyenites of this study are similar to trachytes (they are transitional between quartz microsyenites and microgranite) and thus may be studied using the phase relationships developed for trachytes.

2. The System Ab-Or-An-Q. It has been emphasized (Carmichael, 1963, p. 103) that study of the feldspar crystallization in oversaturated acid liquids (i.e., excess SiO_2) should not be considered solely in terms of their feldspar components. Since the soda microsyenites of this study are oversaturated, the presence of quartz cannot be disregarded, and the system Ab-Or-An-Q ($\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - $\text{CaAl}_2\text{Si}_2\text{O}_8$ - SiO_2) as portrayed by Carmichael (1963) is highly significant.

In this system (Figure 27) the salic components of acid liquids in equilibrium with two feldspars and a silica mineral define a point at one apex of a tetrahedron, the other apices of which are quartz, plagioclase, and alkali feldspar. The curved surface WXYZ (termed "the two feldspar surface") represents the locus of points along which a liquid is in equilibrium with a plagioclase and alkali feldspar. The two feldspar surface approaches, but does not reach, the Ab-Or-Q triangle (the base of Figure 27).

A significant aspect of this system is the thermal valley or unique fractionation curve which extends from the alkali feldspar minimum (M) to the quartz-feldspar boundary curve near X. It is not possible for liquids crystallizing in the feldspar field to cross this valley under any conditions of crystallization (Carmichael, 1963, page 105).

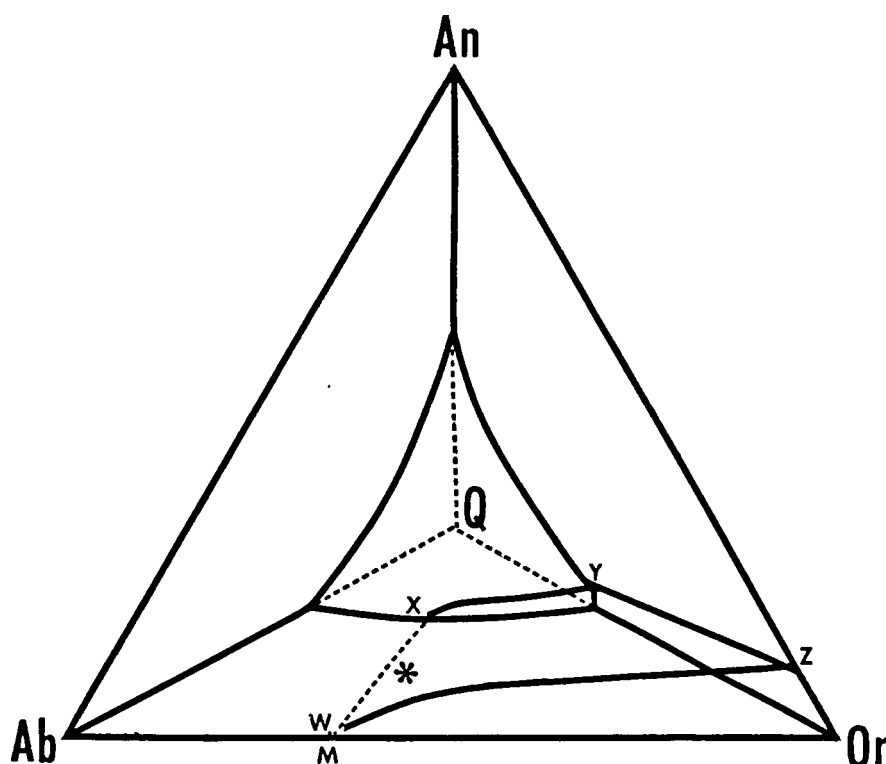


Figure 27. The system Ab-Or-An-Q as envisioned by Carmichael, 1963.

The intersection of the two-feldspar surface with the silica surface (XY, Figure 27) is defined by acid liquids in equilibrium with quartz, plagioclase, and alkali feldspar (Carmichael, 1963, p. 106). Below the intersection acid liquids would be in equilibrium with only quartz and alkali feldspar.

3. The System Ab-Or-Q. Tuttle and Bowen (1958, p. 63-80) have discussed crystallization on the base of this tetrahedron (the ternary system Ab-Or-Q, Figure 28) in some detail. They show that under isobaric conditions there is a ternary minimum (labeled M') on the quartz-alkali feldspar boundary. Thus any liquid in equilibrium with a single feldspar (alkali or plagioclase) and quartz may fractionate toward this minimum along the line E'E. It is important, for the discussions that follow, to note that the liquid fractionation curves in the region Or₃₀ to Or₄₅ quickly converge on, and closely parallel, the thermal valley minimum as

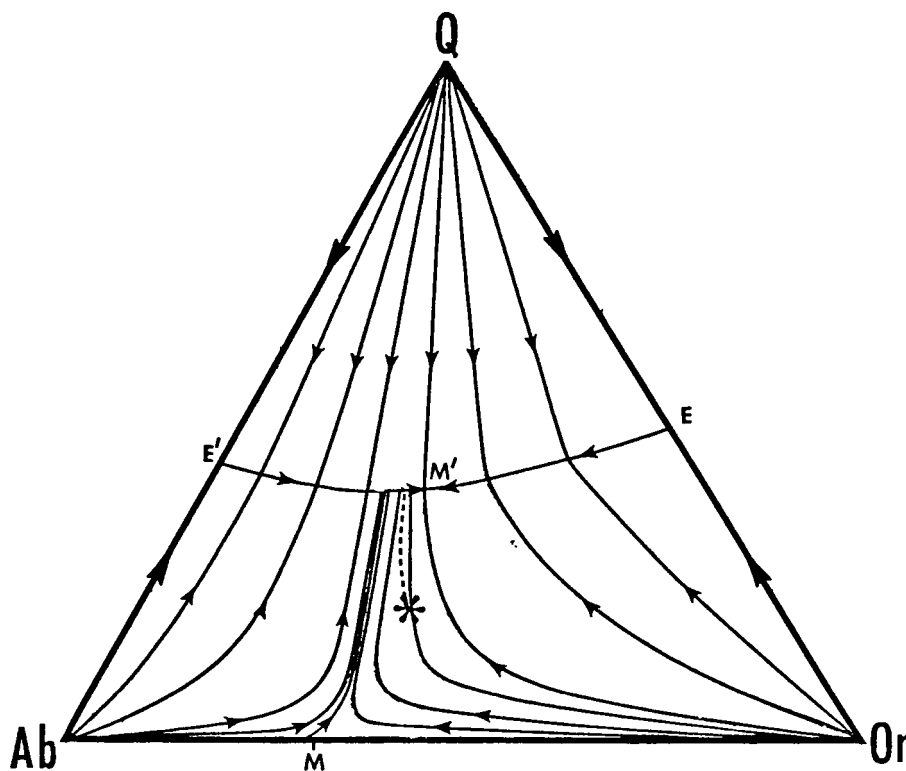


Figure 28. Isobaric fractionation curves for a water vapor pressure of 1000 kg/cm² in the system Ab-Or-Q-H₂O. The relations are projected onto the anhydrous base of the tetrahedron. The dotted line shows the possible curve deduced for the rocks of this study. After Tuttle and Bowen (1958, Figure 30, p.65).

they progress toward the ternary minimum under isobaric conditions. The curves defining liquid compositions for the ternary system, Ab-Or-Q (Figure 28) under conditions of isobaric fractionation most closely resemble the conditions thought to be present during most of the crystallization of the rocks of this study.

Phase Relationships of Mountain 4320 Rocks

In an attempt to trace the crystallization history of the magma in the Ab-Or-An-Q tetrahedron, the composition of the various kinds of feldspar grains are critical. While insufficient detailed knowledge of composition variation within grains and within the intrusion is available, the data at hand can give some limits for a model of crystallization and for testing that model. It is presumed that the cores of the phenocrysts formed earliest, and at least approximate the composition of the first formed feldspar phases. Since both phenocryst and groundmass grains are compositionally zoned, it is reasonable to assume that (a) something approaching early compositions are preserved at the cores of grains, and (b) that some fractionation of the magma occurred during crystallization. Also it is assumed that grains in the peripheral samples, in general, will have had less time to react with the magma and hence give the best idea as to early crystal composition. Accordingly, in the proposed crystallization scheme that follows, the compositions that are given are estimates based on the measured values of Tables 6 and 16.

Figure 29 is a compilation in a portion of the Ab-Or-An-Q tetrahedron (see Figure 27) with the projected isobaric fractionation curves of the system Ab-Or-Q-H₂O (Figure 28). The two feldspar surface is represented

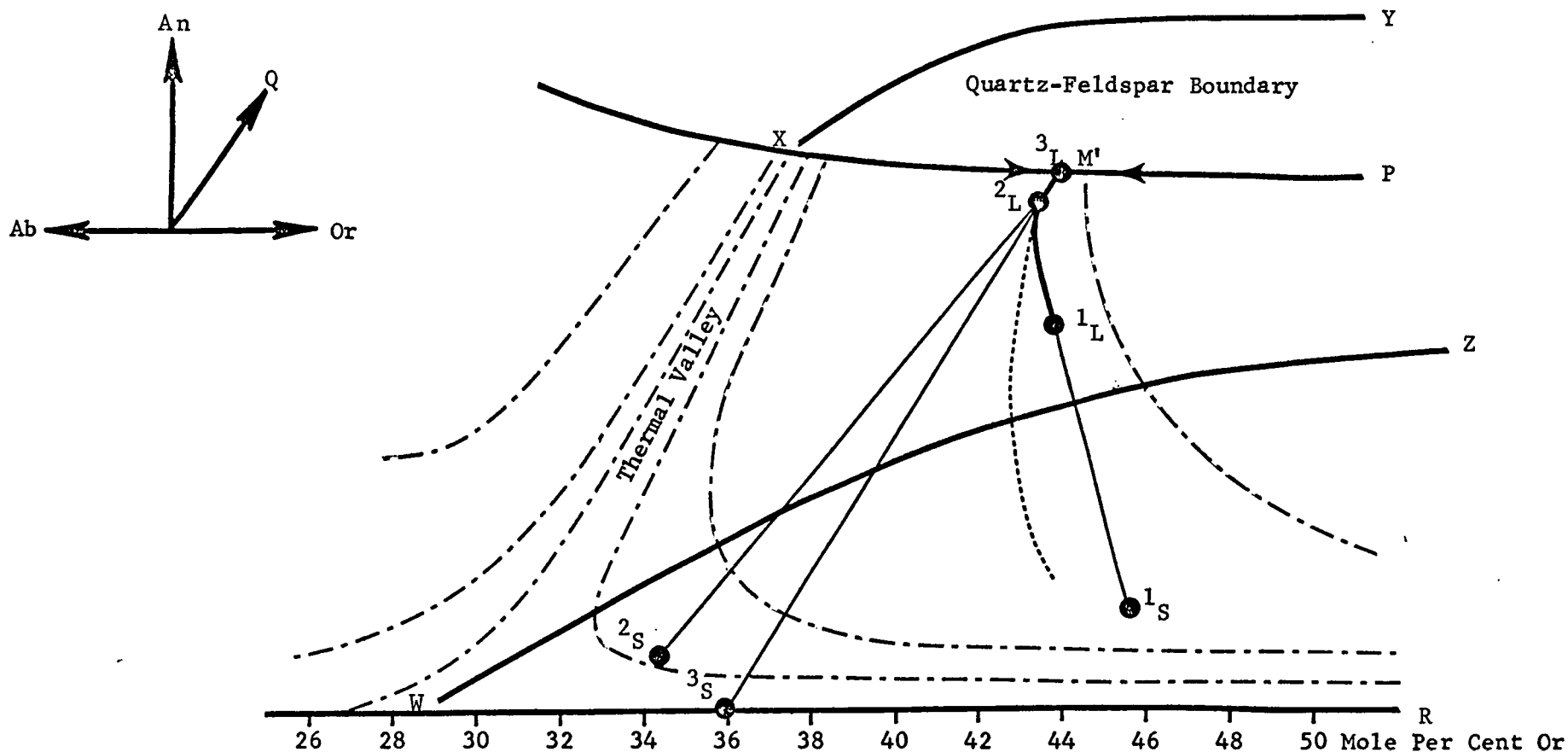


Figure 29. A portion of the system Ab-Or-An-Q showing the fractionation curve for the rocks of this study (data from Figures 28 and 29 and the results of this study). The portion of the system shown ranges from Ab₁₀ to Ab₅₀, Or₃₀ to Or₅₀, An₀ to An₃, and Q₀ to the quartz-feldspar boundary curve.

The liquid path in the tetrahedron is shown with a solid line, and shown projected to the base (Ab-Or-Q) of the tetrahedron with a dashed line. Solid phases noted in the text have s subscripts and are shown projected onto the front (Ab-Or-An) face of the tetrahedron.

by the WXYZ curved surface (after Rahman and MacKenzie, 1969, Figure 1, page 399); the alkali feldspar volume by the space enclosed between the planes XYP and WZR; the thermal valley by the line WX. Point 1_L represents the averaged normative mineralogical composition of samples MC-7 and MC-15. As such, it represents a composition of 44.8 per cent Ab, 33.0 per cent Or, 19.4 per cent Q, and 2.7 per cent An. This point plots 0.3 to 0.4 per cent An below the two feldspar surface (WXYZ).

Since all crystallizing magmas within this system progress toward the alkali feldspar binary minima and then quartz-feldspar boundary, it is logical to predict a similar course for the initial crystallization of this magma. Thus, the analyzed samples of this mass represent a magma crystallizing alkali feldspar phenocrysts of about Or_{45-50} mole per cent composition (eg. somewhat more Or-rich than phenocrysts of periphery, prongs and dikes) represented by tie line $1_L 1_S$. These phenocrysts are relatively enriched in An (up to 1 per cent based on the microprobe data of M. F. Carman), compared to later alkali feldspars. Upon further crystallization, the composition of the magma moved along a curved path (1_L to 2_L) as the relatively Or-rich crystals formed and changed composition from about Or_{45-50} down to about Or_{34} (phenocryst values from main mass center, "core", Table 6, and microprobe phenocryst and groundmass cores from main mass samples, Table 16). Concomitant with this change, the amount of An in the liquid decreased due to preferential removal in these early phenocrysts (microprobe data). Thus the liquid path (1_L-2_L) during the early phase of crystallization moved slightly toward (a) the thermal valley, (b) the base of the tetrahedron, and (c) rapidly toward the quartz-feldspar boundary. No quartz was being precipitated so the liquids were enriched in this constituent.

There was slight fractionation in this portion of the solidification sequence as recorded in the zoned alkali feldspar phenocrysts. The factors producing the fractionation are not known with certainty, but decreases in pH_2O and volatile loss are generally the causes of such disequilibrium. Thus this first stage of crystallization may be representative of the initial movement of the magma to the place of intrusion. Note that this early crystallization trend may not exactly parallel the isobaric trends, since pressure was presumably dropping during the upward movement of the magma.

The effect of the pressure variations and slight disequilibrium conditions on the position of the two feldspar surface is not known. It may very well be that this surface would fluctuate through point 1_L in response to these stimuli.

If the initial liquid was on or above the two feldspar surface, sodium-rich plagioclase would be in equilibrium with the system. According to Carmichael (1963) such liquids would proceed along a path similar to that presented above but on the two feldspar surface.

The magma (bulk rock) composition is certainly near the two feldspar surface, but whether it ever reached that surface (overall or locally) is not certain. The very rare plagioclase phenocrysts suggest this possibility, but it may have been only a rare and local occurrence.

An estimate of the volume of phenocryst and groundmass grain cores in the composition range Or_{34-40} suggests that this initial stage of crystallization continued until the mass was at least 15-30 per cent solid.

Final emplacement of these rocks may have occurred late in the primary stage of crystallization. Localized distinct fluidal textures imply that some parts of the mass were 60 to 80 per cent solid at the time of final movement, but the groundmass grains could have started forming at any time

before this final movement, and their cores thus reflect the composition crystallizing at the end of the primary phase. Since the chilled rocks of this intrusion have an extremely fine-grained groundmass, the larger groundmass grains of the balance of the mass were not fully formed at the time of intrusion. Thus it is most likely that the bulk of groundmass production began as the magma was intruded at hypabyssal depths (around point 2_L , Figure 29). The disequilibrium recorded by the phenocryst zonation may indicate the movement from subhypabyssal conditions to the place of intrusion. The glomerocrysts may reflect a crowding of these phenocrysts as the magma passed through narrow passages.

Since the phenocrysts of the chilled marginal rocks were isolated from the main mass of liquid by the very fine grained and supposedly rapidly formed groundmass surrounding them, no further reaction was possible. Phenocrysts toward the center of the mass were, however, able to achieve a more complete equilibrium with the liquid on cooling, and crystallization continued. Thus the phenocryst Or compositions decrease toward the center of the mass implying a greater degree of equilibrium in its central portions.

The liquid composition then progressed toward the quartz-feldspar boundary (2_L - 3_L , Figure 29) in the second stage of crystallization. This trend, parallel to the thermal valley, reflects removal of Ab + Or from the liquid at a nearly constant ratio as the liquid was being enriched in silica. The An composition of the cores of the groundmass grains (microprobe analyses) appears to be constant at approximately 1 per cent so that the An component was still being removed from the magma, which thus still had a composition above the Ab-Or-Q base of the tetrahedron. During this trend the magma should have been crystallizing groundmass grains of nearly constant composition

of about Or₃₅ or Or₃₄ based on the isobaric fractionation curves and phenocryst and groundmass core compositions (Table 16). The innermost parts of crystals of the first stage of crystallization were reacting with this liquid as well, and producing further zonation and decrease of their total Or content. The mass would likely consist of a thin, completely solid peripheral rind (the chilled zone) and progressively less viscous crystal mush toward the center at this stage of crystallization. The mass is estimated to be 60 to 80 per cent solid at this stage. The termination of this second stage of crystallization was marked by (a) the disappearance of An from the solid phase, presumably all used up, (b) the initiation of quartz precipitation, and (c) Or rich rims developing on the alkali feldspar grains. Thus the liquid was at point 3 on the base of the tetrahedron (no An) and in contact with the quartz-feldspar boundary.

During the third (and last) stage of crystallization the liquid composition moved along the lower edge of the quartz feldspar boundary (3_L-M', Figure 29), being enriched in potassium. At the same time the feldspar composition started moving sharply toward the Or side of the diagram in parallelism with the liquid change giving rise to the observed K-rich rims on phenocryst and coarser groundmass grains. Tuttle and Bowen (1958, p. 65) described a comparable theoretical sequence of composition changes with fractional crystallization.

The final liquid solidified on or before reaching point M'. No indications of early post solidification alteration or deuteric effects were noted. Figure 30 shows the crystallization sequence above projected to the base of the Ab-Or-An-Q tetrahedron.

Discussion

If Tuttle and Bowen's fractionation curves were being followed precisely, it would be very difficult to get Or compositions much below about 40 per cent with the assumed starting liquid; but the probability of varying pressure on the system during intrusion, as well as partial reaction between crystals and liquid, make a precise following of composition along those curves impossible. Moreover, all of the determinative methods so far devised disagree on the order of approximately 2 per cent (Orville, 1963, Tuttle and Bowen, 1958, Wright and Stewart, 1968). Thus, though the precision of relative results presented here is considered to be quite good, their absolute accuracy for comparison with data from another laboratory is in some doubt. Finally, the fractionation curves are drawn for weight per cent, while composition data are given in mole per cent, about 1.5 per cent below weight per cent in the range Or₃₀₋₅₀. All of these factors allow room for the possibility that the crystallization sequence outlined fits published data quite closely, but it also is very probable that in detailed examination the system is more complex and that fractionation curves are measurably different from those deduced by Tuttle and Bowen. That is, the fractionation curve may bend away from the Ab corner as it approaches the quartz-feldspar boundary and the tie line to the alkali feldspar solid phase may move relatively rapidly toward an Ab-rich composition to arrive at compositions as low as Or₃₄, as suggested in Figure 29, 1_s to 2_s, and Figure 30.

These phase relationships just presented are, admittedly, generalized and simplified from what is sure to be a more complex sequence of events. Such unassessable factors as:

- (1) amount, type and the effects of volatiles present;

- (2) complications in the sequence due to the presence of pyroxenes, amphiboles and other minor mineral species; and
- (3) inadequate knowledge of the specific phase relationships in this isolated portion of the system Ab-Or-An-Q by this and previous workers;

are beyond the scope of this study. Further study of these rocks could, quite likely, resolve these complications. The gross aspects of these future explanations will not, in this writer's opinion, vary significantly from those presented above; but they will allow a more detailed specification of the crystallization history.

The crystallization history, as presented, was based primarily on the composition variations detected in this study and the microprobe results of M. F. Carman. Optical and x-ray data support these conclusions, as shown by the facts that:

1. Both phenocrysts and groundmass are optically essentially homogeneous, but x-rays show most to be cryptoperthites. It is thus concluded that the alkali feldspar crystallized as a single phase, the bulk composition of which has the history outlined above.
2. All samples with a high sanidine structural state and a homogeneous phase are phenocrysts at or near the igneous contacts, implying early chilling, and all have high Or contents.
3. All of the main mass core samples are unmixed, with low sanidine structural states and low Or contents as well as anomalous cell dimensions, indicating slower cooling and some adjustment to lower temperatures.

The groundmass samples have high Or contents but are strongly unmixed and have anomalous cell dimensions which indicate very late solidification and considerable adjustment to lower temperatures. The greater degree of unmixing of K and Na phases of the groundmass grains, while retaining an Si-Al ordering comparable to that of the phenocrysts (similar structural state), is unexplained. However, it is known that the presence of H_2O strongly affects unmixing, and the groundmass may reflect a concentration of late hydrous solutions which affected the smaller grains of the groundmass more than the phenocrysts prior to being dissipated from the intrusion.

COMPARISON WITH OTHER IGNEOUS MASSES IN THE REGION

Plots of rocks from the region on triangular variation diagrams (Figure 31) show that the Mountain 4320 soda-microsyenite lies on the main trends of magmatic evolution of the area, as determined by Cameron (1968).

Parent Magma

Alkaline provinces are generally postulated to be derived from olivine basalts (Turner and Verhoogen, 1960, pp. 196-200). Maxwell et al (1967, p. 116) state that olivine basalts are quite widespread in the Big Bend Region and they are among the oldest of the volcanic rocks, implying the presence of basaltic magma at the onset of igneous activity. They postulate that a magma similar in composition to the Alamo Creek Basalt (which has extensive outcrops in the region) is most likely to have been the source for most of the igneous rocks of this region. Differentiation of such a basalt under plutonic conditions wherein most ferromagnesian minerals are subtracted from the system as the residue from filter-pressing, and alkalies and volatiles are concentrated in the supernatant liquid might, conjecturally, produce a magma such as formed these rocks.

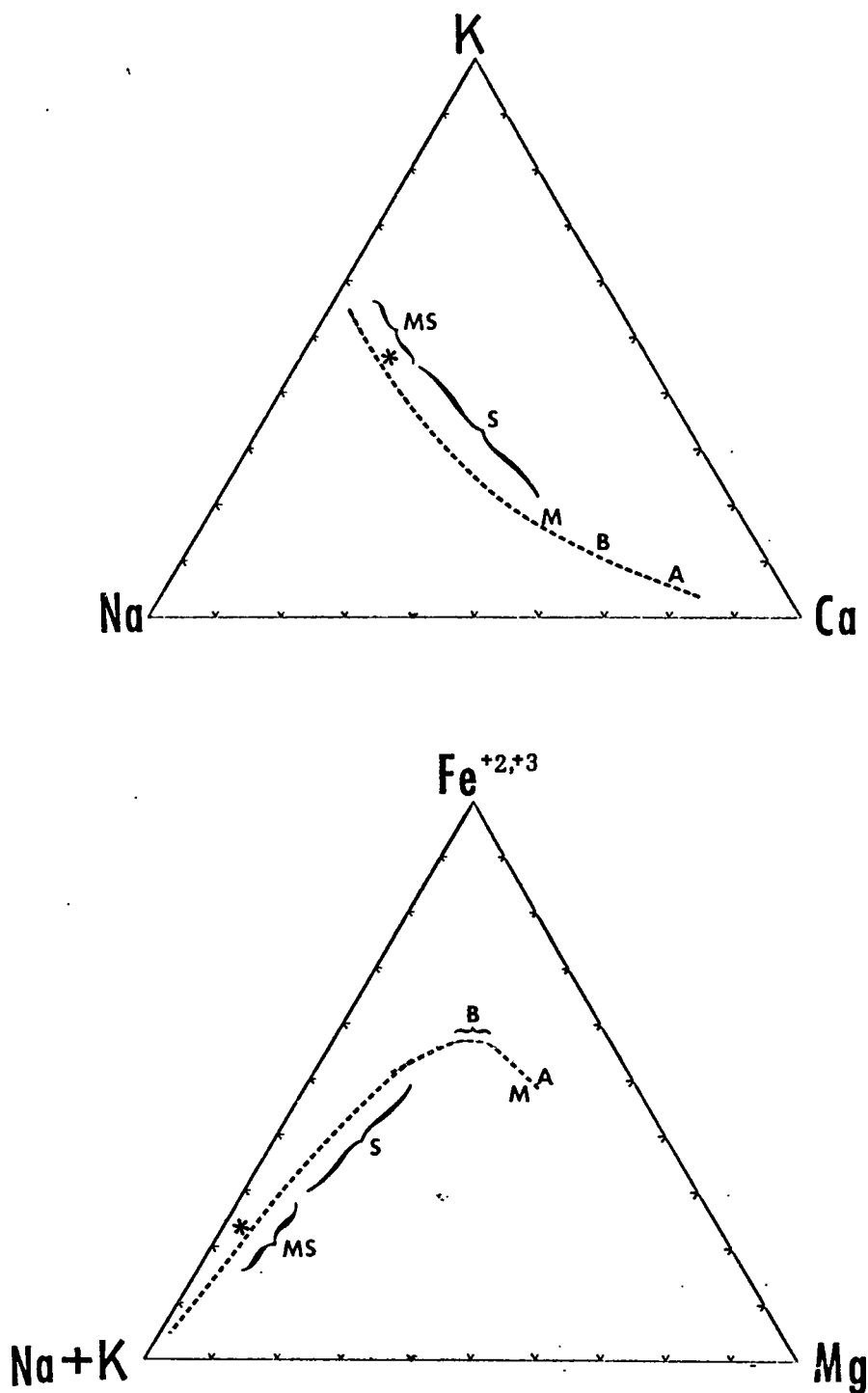


Figure 31. Variation diagrams of igneous rocks of the Big Bend Region compared to the rocks of this study (marked with an asterisk). The relative position of ankaramites (A); basalts (B); malignites (M); syenodiorites, syenogabbros, trachyandesites, and trachybasalts (S); and syenites, microsyenites, and microgranites (MS) are shown for comparison. After Cameron (1968).

CONCLUSIONS

Field Relations

1. The Mountain 4320 main mass intrusion is a small discordant stock or laccolith that outcrops over an area of three-quarters of a square mile.
2. The north and south prongs are sills 500' to 700' thick; they were likely derived from the main mass or from the same parent body as the main mass. Presently there is no visible contact among the prongs and the main mass.
3. The main mass was apparently emplaced in a single pulse, and both the north and south prongs were derived in a single pulse from the main mass liquid or from a very similar liquid.
4. The main mass and the prongs are composed of megascopically homogeneous soda microsyenite.
5. The rock of the main mass is genetically and structurally related to the small microsyenitic dikes in the area, but additional work will be necessary in order to specify details of the relationships.
6. Contact metamorphic effects in the intruded sedimentary rocks, other than volitization of carbonaceous matter, were not detected.

Petrography

1. The modal analyses of this intrusion are relatively constant. Slight variations in the alkali feldspar phenocrysts-to-groundmass ratio, the amount of pyroxene, and the amount of quartz do not correlate with other variations known to be present.

More than 83 per cent of the bulk of these rocks consist of alkali feldspar phenocrysts and felsic groundmass minerals.

2. The preponderance of feldspars are anhedral or subhedral, slightly zoned, cryptoperthitic, polymorphs of alkali feldspar.
3. 2Vx values for the alkali feldspar phenocrysts range from 27° to 57° . Zoning (based on 2Vx determinations) is common with a maximum zoning of 25° 2Vx detected in a single grain. Groundmass 2Vx values range from 18 to 49° 2Vx; maximum detected zoning in a single grain was 15° 2Vx. The groundmass 2V is generally less than the phenocryst 2V of the same sample. Phenocryst samples from the center of the main mass appear to have larger 2V values than samples from the periphery. Based on % Or composition versus 2V plots these samples have low sanidine structural states.
4. The alkali feldspars range in composition from Or₂₈ to Or₄₆ mole per cent. Bulk phenocryst analyses range from Or₂₈ to Or₄₁ mole per cent. The median phenocryst composition is 35 mole per cent Or. There is a definite trend from high composition values at the periphery to lower values toward the center of the main mass. All samples with greater than 36 mole % Or occur at or very near the periphery. The prong samples have minimum, maximum and median phenocryst compositions of 28, 39, and 36 mole % Or respectively which is in the same range as the main mass periphery samples. The dike samples have minimum, maximum and median phenocryst compositions of 38, 41, and 40 mole % Or respectively which are generally higher

than both the main mass and the prong samples. The groundmass samples range from 40 to 46 mole % Or which is generally higher than the phenocryst samples. The median groundmass composition is 41 mole % Or. The groundmass samples from the core of the main mass appear to have higher Or compositions than the periphery samples. The minimum, maximum, and median differences between phenocryst and groundmass compositions from the same sample are 1.8, 15.3, and 7.6 mole % Or respectively.

5. The preponderance of samples analyzed had low sanidine structural state for the K phase; exsolved, cryptoperthitic mixtures of K and Na alkali feldspar phases; and anomalous cell dimensions. Rare phenocryst samples (invariably from the prongs, dikes, or main mass periphery) had high sanidine structural states, normal cell dimensions, and contained a single homogeneous alkali feldspar phase. Phenocryst samples with a homogeneous alkali feldspar phase have higher mole % Or concentrations than phenocryst samples with exsolved phases.

Groundmass samples invariably have low sanidine structural states for the K phases, anomalous cell dimensions, and consist of exsolved K and Na phases.

All exsolution detected is on a cryptoperthitic scale.

All samples with homogeneous alkali feldspar phases have normal cell dimensions.

Compositions calculated by the three peak method vary 2 to 5 mole per cent Or from the composition calculated by ^{20}O ($\bar{2}01$) direct.

There is a distinct gradation from high $\Delta \bar{201}$ values at the center of the main mass to lower values at or on the periphery. Low $\Delta \bar{201}$ values are common in both dikes and the prongs. Groundmass $\Delta \bar{201}$ values are invariably greater than the associated phenocryst values.

Microprobe analyses appear to confirm the composition variations found in this study and provide the resolution necessary for intragrain composition determinations which are needed for an accurate prediction of the crystallization history.

Petrochemistry

1. The Mountain 4320 rocks are alkalic, subaluminous, and distinctly oversaturated with respect to silica. They are among the most common, based on composition, of the rocks of Washington's Tables with more than 80 per cent normative Ab+Or+Q.
2. The Mountain 4320 rocks lie on the main differentiation trend of the Big Bend Region of Trans-Pecos Texas.
3. The deduced sequence of crystallization, and composition and structural phase relations show the alkali feldspars to agree well with what is known of the phase relations in the system Ab-Or-An-Q as refined by the known fractionation relationships in the system Ab-Or-Q. In addition, these data confirm some laboratory-derived relations and may refine the known relations with additional study.

Petrogenesis

1. Crystallization of these rocks began at or near the two feldspar surface of the system Ab-Or-An-Q .

2. The crystallization sequence may be logically subdivided into three segments as discussed.

Analysis Methods and Techniques

1. The method recommended for concentration of the alkali feldspar phenocrysts (Appendix 1) works well on fresh samples, but is ineffective on weathered samples. All samples must be microscopically examined for purity after separation and before further processing.
2. The method adapted for homogenization of the alkali feldspar polymorphs (Appendix 2) was sufficient for most samples. Each sample apparently requires individual consideration to achieve complete homogenization, however. Thus all samples should be checked for perfection of homogenization before internal standards are added, so that additional heat treatment can be done when necessary.
3. The method of analysis for determination of Or concentration (Appendix 3) is sufficiently accurate and reproducible ($\pm 1.5\%$ Or) for routine application on hypabyssal rocks similar to those studied. 72 per cent of the analyses attempted gave acceptable or better results. Most poor composition data are the result of incomplete homogenization and rarely due to machine or operator error. Although the technique is less accurate in the range Or_{30} to Or_{45} (Orville, 1963) than at other compositions, these data prove it to be of acceptable accuracy. Had the total Or variations of these rocks been only 4 or 5 per cent Or, this would not have been the case.

Thus the technique is useful only when the range of $\Delta\bar{201}$ variation expected is 5 per cent or more.

4. The method adapted for estimation of alkali feldspar polymorph structural state is, as it was intended (Wright, 1968) of value in approximating the structural state of these samples. The accuracy of the method will not be known until structural state refinement data are available.

The $\Delta\bar{201}$ values which were calculated for all analyses show sympathetic variation with both composition and structural state. The generally low quality of these data is because of the poor representation of the potassium $\bar{201}$ peak. The reason for its poor quality is no doubt a function of the amount present, but other factors such as a range of structural states for the K phase may also be contributing to its inferiority. Data from these analyses indicate that the minimum separation between the potassium and sodium $\bar{201}$ peaks is approximately $0.7^\circ 2\theta$ before indications of a homogeneous phase are apparent. This indirectly implies that the adjustment from a homogeneous phase to slightly exsolved phases occurs without simple bifurcation and separation of the $\bar{201}$ peaks. These conclusions thus indicate that a perfect gradation of states between the homogeneous and the slightly unmixed states ($\Delta\bar{201} < 0.7^\circ 2\theta$) does not manifest itself in the $\bar{201}$ peak position and separation data of this study. Recall that the $\bar{201}$ peaks reflect cell parameters in the "a" and "c" direction so that the statements above could now be recast in terms of the "a" or "c" cell dimension. Change

in "a" seems most likely since $\bar{2}01$ is most sensitive to variations in "a"; "c" changes relatively little with change in composition. The alkali feldspar polymorphs from this intrusion are ideally suited for the study of unit cell adjustments in response to unmixing by unit cell refinement methods.

5. The procedure adapted for quantitative determination of quartz (Appendix 6) cannot be adequately evaluated at this time. The results do not appear to be consistent with the results expected from optical examination or from the normative mineralogy.

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APPENDIX 1

Method for the Concentration
of Alkali Feldspar Phenocrysts
In This Study

Because of the evenly-distributed, fine-grained iron oxides and paramagnetic pyroxenes present in the groundmass of unaltered samples, relatively pure concentrations of the feldspar phenocrysts were obtainable by electromagnetic methods. Details of the technique follow:

1. Crush 5 to 15 grams of the fresh rock, and sieve. The less-than-30 mesh, greater-than-60 mesh fraction generally gave the richest phenocryst residue after separation for these samples.

2. Wash this 30-to-60 mesh fraction in water, decant, and air dry. This removes the rock flour adhering to the grains which affects its magnetic properties.

3. Adjust the magnetic separator (a Frantz Isodynamic Separator, Model L-7, was used in this study) to a side slope setting of 10° and a forward slope setting of 22° .

4. Pass a strong permanent magnet over the ground sample to remove the ferromagnetic particles.

5. Pass the sample through the separator at a setting of 0.25 amps. Rerun the nonmagnetic portion of the sample again at a setting of 1.0 amps. Make one or more passes of the nonmagnetic portion of the sample at 2 amps for final purification.

6. Inspect the nonmagnetic portion of the sample with a microscope for purity.

These grain sizes and machine settings were arrived at by trial and error methods, and vary slightly from sample to sample or day to day operation. In general, adjustments of the side slope angle (from 2° to 15°) were able to compensate for most variations encountered in the rocks of this study. Badly-weathered samples could not be separated by this technique, and had to be hand-picked.

APPENDIX 2

Method for Homogenization
of Alkali Feldspars by Heat-Treatment

The techniques enumerated below are patterned after similar techniques recommended by Orville (1963), and Wright and Stewart (1968). The techniques were tested and adapted early in this work based on a small pilot study of representative samples. Four phenocryst samples (I-4, I-6, VI-3, and Dam 3) and two groundmass samples (IV-11, VI-3) were tested.

The phenocrysts were heated at 1000°, 1050°, and 1100° C. for 8, 24, 48, 192, and 336 hours. Homogenization was complete and reproducible at 1050° C. in 48+ hours. Shorter times gave erratic results, lower temperatures gave incomplete homogenization, higher temperature fused the grains, and longer times produced no detectable effect beyond 48 hours at 1050° C. The groundmass samples were treated at 900°, 950°, and 1000° C. for 8, 24, 48, and 192 hours. Homogenization was complete and reproducible at 950° C. in 48+ hours. The relatively fast homogenization time (48 hours) is to be expected for high structural state alkali feldspars. Many investigators have commented on the apparent correlation between relative structural state and ease of homogenization.

Details of the homogenization technique follow:

1. The sample (as pure as possible) is folded into a 2 cm.-square piece of platinum foil. The foil and enclosed sample are placed in a platinum crucible (no top is necessary).

2. Heat treatment occurs in a pre-heated, thermostat-controlled oven (a Leco, Model 540-1 oven with thermocouple pyrometer was used for this study) for 48+ hours.

3. After cooling, the sample is removed from the foil by flexing or by burnishing with a rounded glass rod.

4. The $\bar{2}01$ peak of the alkali feldspars is a good indicator of homogeneity, and thus effectiveness of heat treatment. Inhomogeneous samples do not have a sharp termination on the $\bar{2}01$ reflection, indicating more than 5 per cent of a second phase is present. In this study, peaks with a "C" rating (as described in Appendix 7) or better were assumed to be homogeneous.

In assembling the data for this paper and rating the composition determinations, some (20-30 per cent) of the unacceptable determinations appeared to be inhomogeneous. Since homogenization checks were not routinely run after the first 45 samples, the inhomogeneities were not detected until after addition of the standard. Hence, additional heat treatment of these samples was not possible. This leads to the conclusions that (1) each analysis should include a homogenization check, and (2) though the recommendations above suffice for most samples, each sample requires individual consideration to achieve complete homogenization.

APPENDIX 3

Method for Estimation of Composition
(Percentage of Or) Using "d"($\bar{2}01$)

Two methods were used in this study for alkali feldspar composition determination. Both measure the angular separation between the $\bar{2}01$ peak of feldspar and an internal standard. Initial analyses were run using the $(10\bar{1}0)$ peak of quartz as the standard, as recommended by Tuttle and Bowen (1958). This method gave satisfactory results, but the $(10\bar{1}0)$ peak could interfere with Or-rich samples so that the method recommended by Orville (1967) was later adopted. This method utilizes the (101) peak of KBrO_3 (reagent grade) as the internal standard, and is recommended because:

1. Standard grade KBrO_3 is readily available;
2. Natural quartz is then detectable in these samples;
3. No interference between standard and sample occurs.

Details of the technique follow:

1. Make a standard slurry mount of the homogenized sample (natural samples are homogenized by heat treatment, see Appendix 2 for details) mixed with pure and calibrated KBrO_3 (or SiO_2). Mix enough standard with the sample so that $(101) \text{KBrO}_3 \approx 20.23^\circ 2\theta$ or $(10\bar{1}0) \text{quartz} \approx 20.88^\circ 2\theta$ peak is approximately the same intensity as the $\bar{2}01$ peak of the sample.

2. Oscillate the sample through the range 19° to $23^\circ 2\theta$ six times using $\text{CuK}\alpha$ radiation. Goniometer scan speed should be $\frac{1}{4}^\circ 2\theta$ per minute and chart speed 1 inch per minute. In order to achieve high precision, the sample must be oscillated up three times and down three times through this range.

3. Measure the six standard-to- $\bar{2}01$ spacings ($=\Delta 2\theta$) in degrees 2θ to two decimal places. The composition data were graded according to (a) the range or spread of the $\Delta 2\theta$ (feldspar-standard) values, and (b) according to peak shape (in effect, the ability to find the peak center). Details of the data grading conventions used in this study are presented in Appendix 7.

4. Using the averaged value determined, calculate the " d " $\bar{2}01$ for the sample. Enter this value on Figure 32 if KBrO_3 was used, or Figure 33 if quartz was used, and read off the approximate mole percentage Or composition.

Note: In this and all other instances where peak measurements were made in this study, the highest point of the peak was measured if it appeared to be on center. In instances where the highest point on the peak was obviously off center, the measurement was made at two-thirds of the peak height.

The detailed accuracy of this method depends on two critical factors:

- a. The d -spacing of the standard must be known very closely and it was found that natural $\text{CaF}_2(111) + \text{Quartz}(10\bar{1}0)$ spacings have variations on the order of $.0015 \text{ \AA}$ which is sufficient to cause an error of 1.5 to 2.0 % Or. Top grade artificial CaF_2 is not so variable, but even it must be ground, heated, and annealed several times before the correct cell dimensions result. All standards must be checked against a very well-known standard such as Gibb's spinel or diamond.
- b. The second factor is not yet resolvable. There are discrepancies on the order of 2-3 % Or between the various determinative curves in the literature (Tuttle and Bowen, 1958, using quartz; Orville, 1967, using KBrO_3 ; and Wright and Stewart, 1968, based

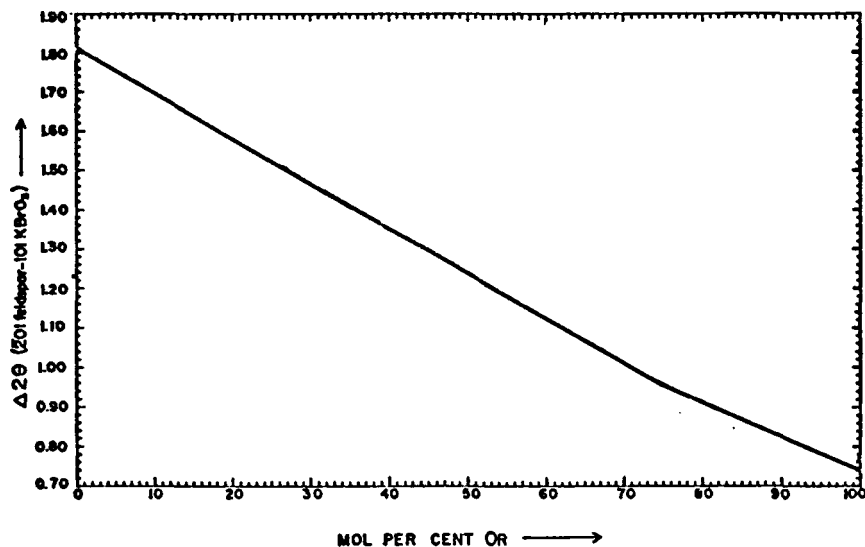


Figure 32. The sanidine-high albite $\Delta 2\theta$ determinative curve for KBrO_3 internal standard. After Orville (1967, Figure 8, p.75).

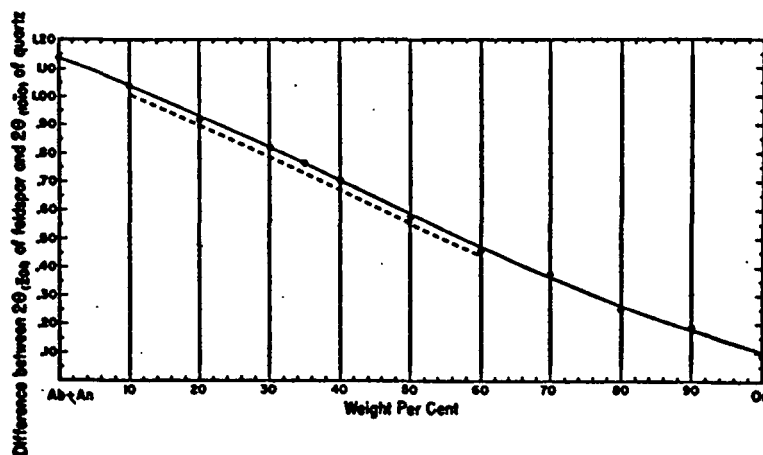


Figure 33. The sanidine-high albite $\Delta 2\theta$ determinative curve for quartz internal standard. The dashed line is used for conversion to mole per cent. After Tuttle and Bowen (1958, Figure 4, p. 13).

on CaF_2). This gives a built-in uncertainty of results, especially for comparing work from different laboratories. However, it is apparent from repeats and crosschecks done for this work and elsewhere that when using the same standard on a given group of samples in a single laboratory, the precision of measuring is well under 0.5% and reproducibility is within $\pm 1.5\%$ on different runs.

APPENDIX 4

Method for Determination of
Structural State of Alkali Feldspar

These instructions are patterned after the recommendations of Wright (1968, pages 92 to 100).

1. Using a standard slurry mount of the ground sample (natural), mixed with pure (and calibrated) CaF_2 , run a pattern from $2\theta = 57^\circ$ to $2\theta = 13^\circ$ using $\text{CuK}\alpha$ radiation ($\lambda = 1.5418 \text{ \AA}$) and a goniometer and chart speed yielding $1^\circ 2\theta = 1''$.

2. Measure to two decimal places the separation between the (111) $= 28.30^\circ 2\theta$ and (220) $= 47.02^\circ 2\theta$ reflections of the CaF_2 . Make corrections for paper shrinkage and extension using this guide.

3. Check the position and shape of the $\bar{2}01$ reflections $\approx 20.8^\circ$ to $22.1^\circ 2\theta$. Determine whether the feldspar consists of a potassic phase, sodic phase, both, or a homogeneous phase, and whether the phases have a limited or a broad range of composition. In this study, the data quality (or composition range) for these structural state determinations were graded by peak shape as indicated in Appendix 7.

4. Measure to two decimal places the 2θ values for $\bar{2}01$, 060, and $\bar{2}04$ for both K and Na phases, if available, and apply the necessary paper corrections as determined in #2 above.

5. Plot the 2θ values of 060 and $\bar{2}04$ on Figure 17 and read the approximate 2θ value of $\bar{2}01$ from the contours. If this value agrees within $0.1^\circ 2\theta$ with the 2θ value observed, the feldspar is considered to have normal cell dimensions. If the 2θ value of $\bar{2}01$ read differs from the observed value by $0.1^\circ 2\theta$ or more, the feldspar is termed anomalous.

6. For normal feldspars the structural state is obtained directly from Figure 16 in terms of the closest plotted feldspar of known structural state for cation-exchanged feldspars (Wright and Stewart, 1968, p. 27). Natural albite and anorthoclase should be compared to the equivalents of high albite and low albite. Natural potassium-rich feldspars should be compared to the equivalents for high sanidine and maximum microcline.

7. The "apparent" structural state of anomalous feldspars may be derived in the same way as for normal feldspars.

8. Record the presence or absence of quartz (a check on the purity of the sample).

APPENDIX 5

Terminology for Alkali Feldspar Polymorphs

A consistent terminology for defining and describing alkali feldspars was proposed by T. L. Wright and D. B. Stewart in 1968, and has been used in this paper. The terminology was one of the results from their study of alkali-exchange effects in the alkali feldspars. The definitions they gave were based on properties of homogeneous phases that contain no greater than 5 per cent of feldspar components other than KAlSi_3O_8 and $\text{NaAlSi}_3\text{O}_8$. In the same paper, they indicate that the effect of additional components is negligible and that these definitions may be applied to any naturally-occurring alkali feldspar. In this classification, feldspars are named on the basis of composition and structural state. Structural state is specified by reference to the alkali-exchange paths on a "b-c" plot (Figure 34, after Wright and Stewart, 1968).

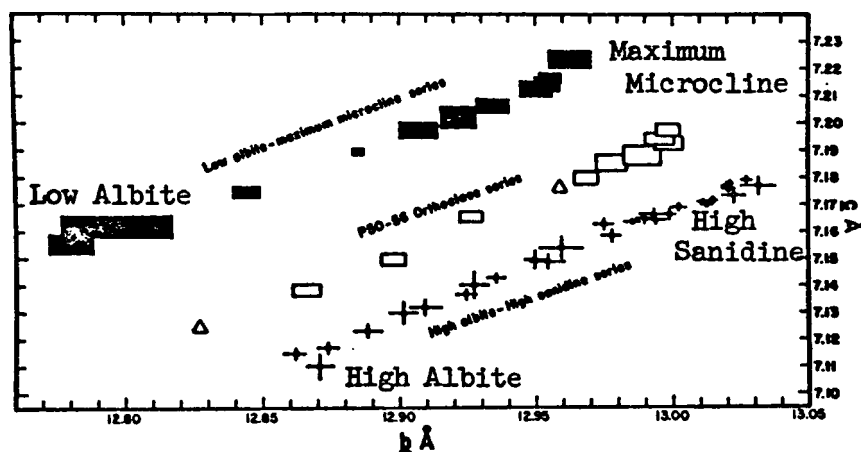


Figure 34 "b" plotted against "c" for alkali exchanged feldspars. After Wright and Stewart (1968, Figure 2a,p.46).

The range of structural states specified for potassic feldspar are as follows:

"High sanidine."⁽¹⁾ Monoclinic. Axial dimensions "b" and "c" correspond to those in the high sanidine-high albite series." (Figure 34)

"Low sanidine."⁽¹⁾ Monoclinic. Axial dimensions "b" and "c" fall between those which define the P50-56F equivalent and the high sanidine equivalent series." (Figure 34)

Open circles. High sanidine—high albite. Data of Donnay and Donnay (1952) re-refined

Solid circles. High sanidine—high albite. Data of Orville (1967).

Open rectangles. Orthoclase series structurally equivalent to P50-56F.

Open triangles are interpolated or extrapolated points in this series.

Solid rectangles. Maximum microcline-low albite. Data of Orville (1967).

All data points are drawn to ± 2 percent Or and to ± 2 standard deviations of the cell parameter.

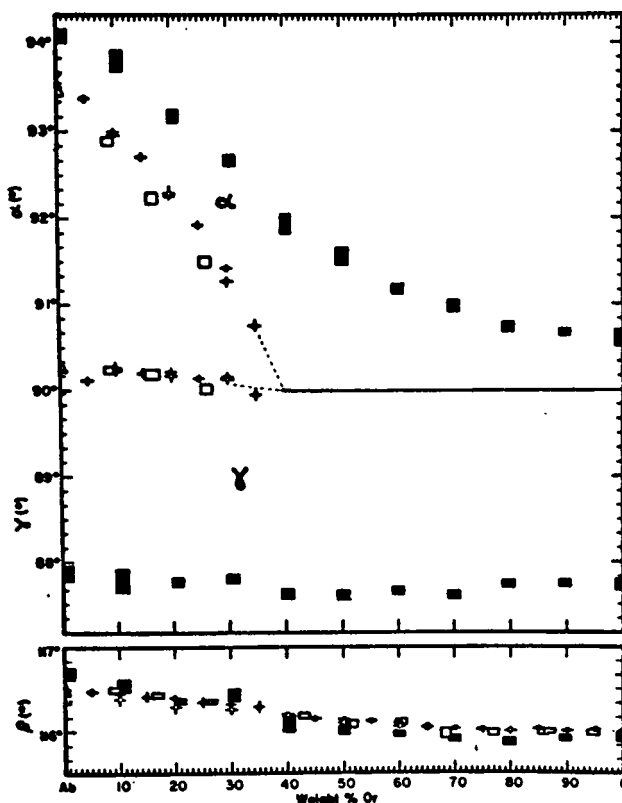


Figure 35. Unit-cell parameters for three structure-equivalent series of alkali feldspars plotted as a function of Or content. After Wright and Stewart (1958, Figure 1c, p.44).

⁽¹⁾The exact position of both the high and low sanidine fields as used in this study are shown in Figure 20.

"Orthoclase. Monoclinic. Axial dimensions "b" and "c" fall along the curve for P50-56F equivalents or between the P50-56F and maximum-microcline equivalent series, if $\alpha = \gamma = 90^\circ$." (Figure 34)

"Intermediate microcline. Triclinic. α , γ , b and c are distinct from the maximum microcline-low albite series." (Figures 34 and 35)

"Maximum microcline. Triclinic. Unit-cell parameters α , γ , b and c correspond to the maximum microcline-low albite." (Figures 34 and 35)

The range of structural states of sodic feldspars are as follows:

"High albite. Triclinic. Contains less than 5 per cent Or component. Unit-cell parameters "b" and "c" correspond to the sodic end-member of the high sanidine-high albite series." (Figure 34)

"Intermediate albite. Triclinic. Contains less than 5 per cent Or component. "b" and "c" fall between the curves for the two limiting series." (Figure 34)

"Low albite. Triclinic. Contains less than 5 per cent Or component. Unit-cell parameters "b" and "c" correspond to the rock's end-member of the maximum microcline-low albite series." (Figure 34)

"Anorthoclase. Triclinic. Contains greater than 5 per cent Or component, but less than 40 per cent Or. Anorthoclase is distinguished from albite by its potassium-rich composition and from the sanidines by its triclinic symmetry."

This terminology is tabulated in Table 19.

Table 19.

<u>Sodic Feldspars</u>		<u>Structural State</u>	<u>Potassic Feldspars</u>
<u><5% Or</u>	<u>>5<40% Or</u>		
High Albite	Anorthoclase	Highest	High Sanidine
Intermediate Albite			Low Sanidine
Low Albite			Orthoclase
			Intermediate Microcline
			Maximum Microcline
		Lowest	

APPENDIX 6

Procedure for Quantitative Determination
of Quartz by X-Ray Diffraction

An x-ray procedure was developed for this study because of the difficulty in making unequivocal optical identification of very fine-grained quartz. Determinations by x-ray of the weight per cent were used as a refinement of point counts of the rock (in which quartz and feldspar groundmass were combined as "felsic groundmass") to yield the results presented as modal analyses (see Table 20). Many techniques were attempted; using the thin sections as the x-ray sample, powder-pack x-ray samples, peak measurement by area under the curve, peak height, etc., but the procedures recommended below gave the most reliable and reproducible results.

A. Procedure:

1. Examine thin section (or preferably, make the point count first) for secondary quartz, since all quartz determined in this procedure is assumed to be primary. If secondary quartz is present, it should be counted separate from the "felsic groundmass" for the modal analysis results.
2. Grind a representative portion of the unweathered sample (for this study, 10 to 11 grams) to 5 - 15 μ in size. A Bleuler eccentric grinder with tungsten-carbide mortar and a 1.5 minute grind time was used for these rocks.
3. Using standard x-ray slurry cement (acetone and Duco cement for this work) make a thick slurry slide (from 1 to 3 mm. thick). The maximum sample thickness, usually critical in diffraction work, is immaterial for this analysis, as the peak locations are not important.

TABLE 20
Quantitative X-Ray Diffraction
Determination of Quartz

Sample Number	20 Sec. Fixed Time Analysis			Total Quartz Count	(2) Per Cent Quartz
	Number of Analyses	(1) Average Count	Average Background		
C-6	3	12,889	1.261	11,628	1.2
D-1	3	19,664	1,104	18,560	6.2
D-11	3	11,923	1,313	10,610	0.9
D-18	4	12,513	1,353	11,160	1.1
D-26f	3	11,343	1,212	10,131	0.9
Dam 1-2	4	15,177	1,373	13,804	1.8
E-3	3	10,920	1,390	9,530	0.7
E-24	3	14,779	1,369	13,410	1.7
G-1	3	16,027	1,470	15,880	2.9
H-5	3	11,683	1,238	10,445	0.9
L-9	14	12,650	1,279	11,241	1.1
L-15	3	16,549	1,299	15,250	2.4
IV-11	9	13,390	1,370	12,020	1.3
VI-3	6	16,987	1,338	15,640	2.7
VI-7	3	15,582	1,382	14,200	2.0
VI-11	3	13,055	1,240	11,815	1.2

(1) At maximum peak amplitude

(2) From Figure 36.

4. Find the highest position of the quartz ($10\bar{1}1$) peak around $26.6^\circ 2\theta$ by scanning slowly through this range.

5. Set the goniometer on the highest position of the peak, and using machine setting identical to those used in the standard runs (for this study, $\text{CuK}\alpha$ radiation at 45 Kv, 30 Ma, with a proportional counter) make a 20-second-fixed-time count.

6. Move goniometer to a representative background free of peaks (26.4° was used in this study; no interfering peaks at this spot were ever noted) and make a 20-second-fixed-time count. Record background count and subtract from the apparent quartz count for total-quartz count.

7. Repeat steps 5 and 6 twice more for a total of 3 counts.

8. Move goniometer up $0.1^\circ 2\theta$ from the estimated maximum peak position and repeat steps 5 through 7. Continue until the total quartz counts definitely are decreasing below previous readings.

9. Move goniometer down $0.1^\circ 2\theta$ from the estimated maximum peak position and repeat steps 5 through 7. Continue until the total quartz counts definitely are decreasing below previous readings.

10. Select the highest set of quartz counts and average the three total quartz readings for calculation purposes.

11. Plot the averaged total quartz count on Figure 36 to find the per cent quartz present and the experimental ranges.

Figure 36 was derived for the rocks of this study by increment addition and dilution of quartz in a control sample (IV-11). Similar calibration curves can be generated for other groups of rocks by using the procedures recommended below:

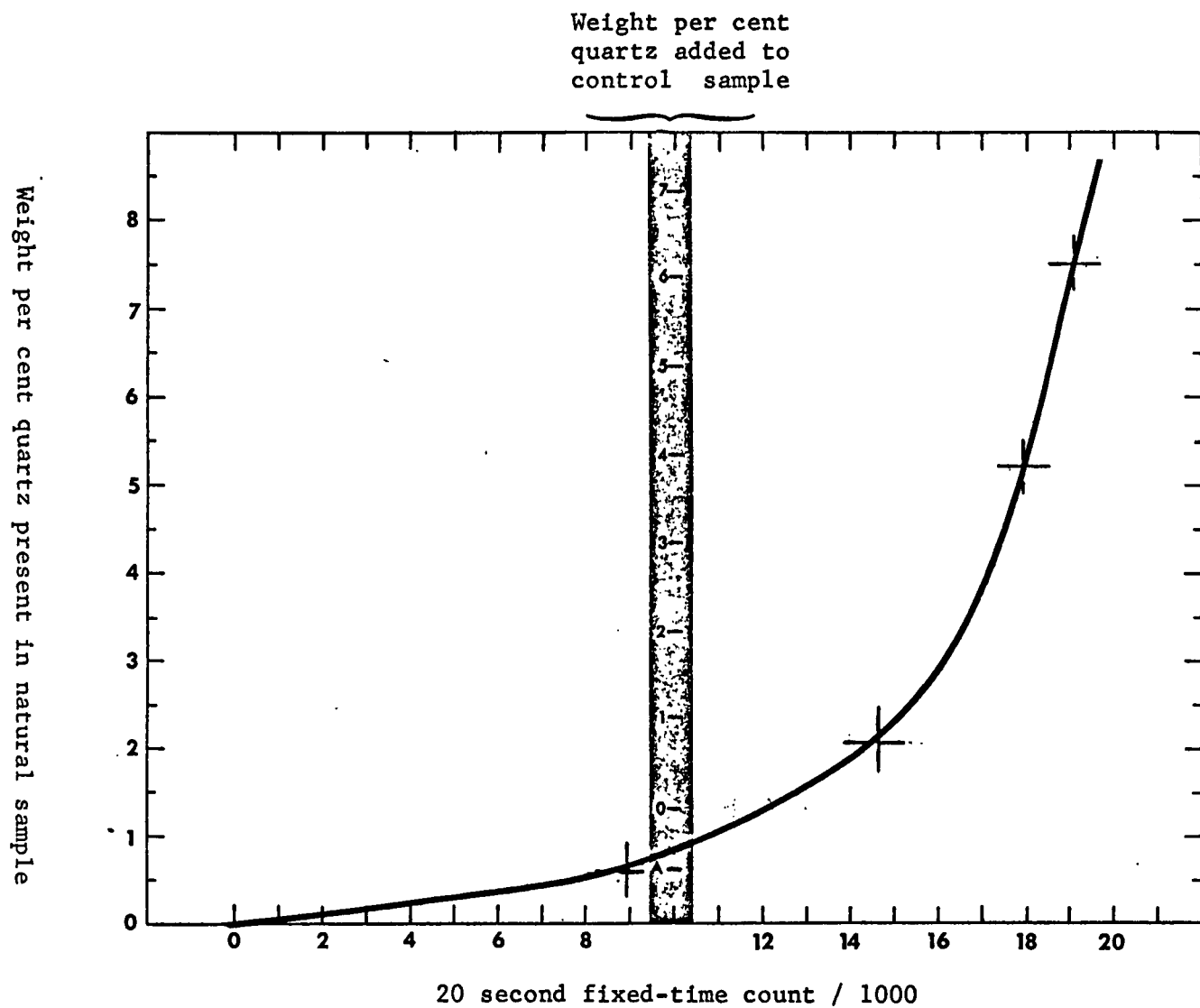


Figure 36. Plot of the 20 second fixed-time count against per cent quartz for the samples of this study.

B. Procedures:

1. Select a representative rock (control sample) and grind as described above.
2. Add known weights of quartz in the range expected for the samples. For this study, quartz was added in the amounts of 0.72%, 3.88%, and 6.10%.
3. Process as described in Procedure A, steps 4 through 10 above.
4. Plot the fixed-time quartz count against per cent quartz added to the control sample (see Figure 36, shaded portion).
5. Select portions of the control sample free of natural quartz. Mix this quartz-free material with known amounts of quartz to establish the amount of quartz naturally present in the sample. For this study, hand-picked, quartz-free alkali feldspar phenocrysts were mixed with 0.47, 0.96, and 1.42 per cent quartz. Process these as described in Procedure A, steps 4 through 10 above. Plot the 20-second-fixed-time count for these against per cent quartz added as in Figure 37. From this plot calculate the amount of quartz naturally present in the control sample. Thus for this study the natural quartz reading of 12,083 counts/20 seconds corresponds to 1.3 per cent added quartz.
6. Return to Figure 36 and equate the amount of quartz in the control sample with zero quartz addition. Erect a new ordinant for per cent quartz present.
7. Check this calibration against other standard samples before final acceptance. For this study an addition control mixture was made by diluting the natural sample 1:1 with quartz-free alkali feldspar phenocrysts.

TABLE 21
Data Used to Prepare Figure 36

Wt. % Quartz Added	Number of Analyses ⁽¹⁾	Averaged Count	Averaged Background	Total Quartz Count
0.0	12	13,453	1,370	12,083
0.72	9	15,973	1,350	14,623
3.88	6	19,322	1,343	17,979
6.10	6	20,376	1,387	18,989
-50% ⁽²⁾	6	10,308	1,326	8,982

(1) All analyses performed on sample IV-11.

(2) Sample diluted 1:1 with alkali feldspar phenocryst.

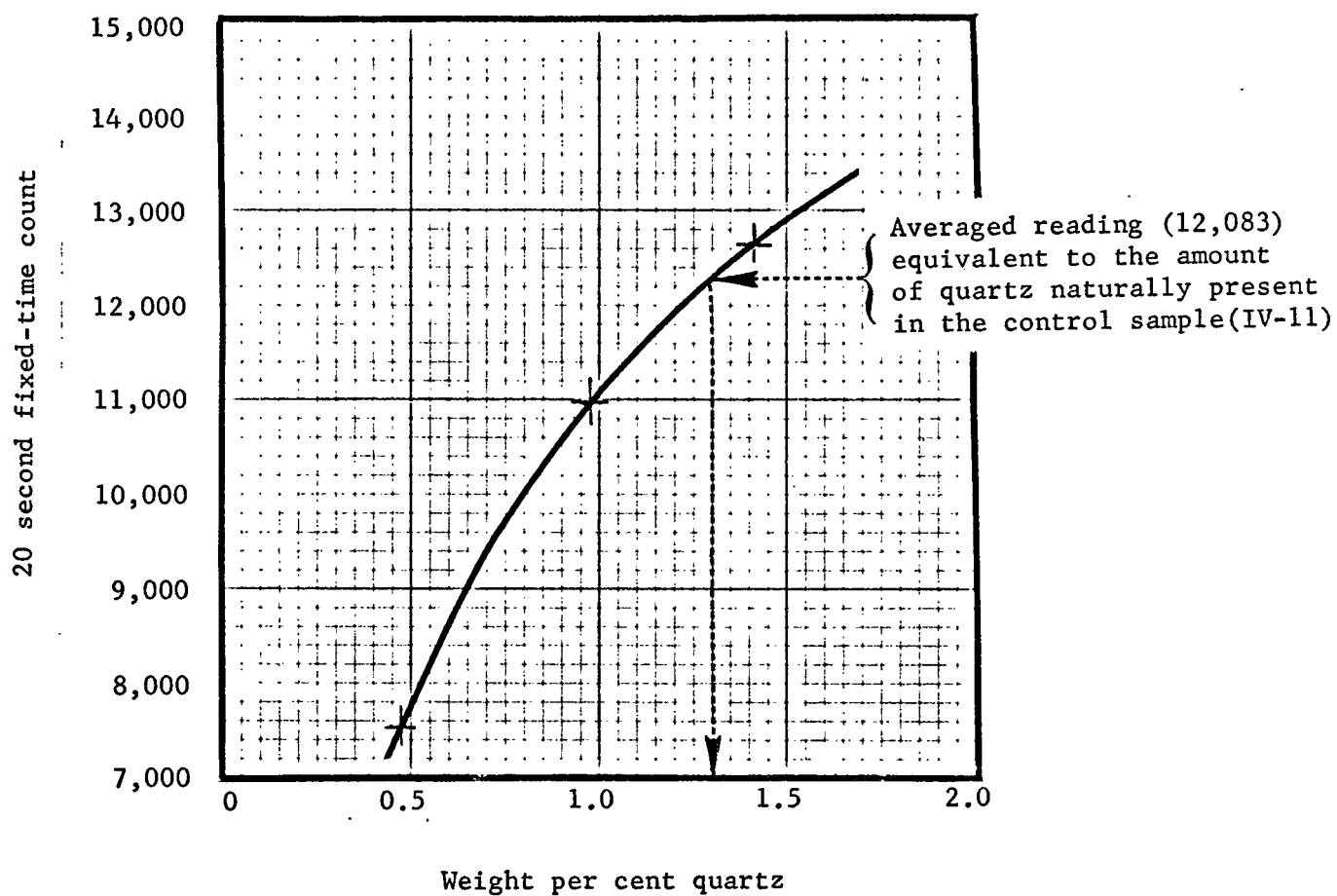


Figure 37. Plot of the 20 second fixed-time count against per cent quartz added to a quartz-free control sample.

The resultant determination (Table 21 and Figure 36 point A) is 0.625 per cent quartz, exactly one-half of the amount estimated to be naturally present in the control sample.

The procedures outlined above are based on the assumptions that:

1. the mineral being determined is not liable to preferred orientation (due to cleavages, preferred crystal growth forms, etc.);
2. the mineral is randomly distributed throughout any one sample;
3. the diffraction matrix and its x-ray absorption properties are similar in all samples;
4. no other mineral peaks interfere with the peak being measured;
5. the mineral being determined is detectable in the range of interest for the study (i.e. lower limit of detectability is sufficiently high for usable results).
6. a sufficiently accurate and reproducible standardization curve is obtainable.

For this study the rocks studied and quartz as the mineral being investigated adequately satisfy the above requirements, and thus these analyses are thought to be adequate for incorporation in the modal analyses for this study.

An interesting finding resulting from the attempts at using the thin section for the x-ray sample was that the calculated percentage of quartz using procedures similar to those outlined above varied over great ranges within one thin section. One sample (VI-11) gave determinations of from 0.8 per cent to 15 per cent quartz over the thin section. Preferred

orientation was discarded as a possible cause of this anomaly by optical examination and by rotating the specimen in the plane of the x-ray sample holder (identical percentages were recorded). This appears to be proof of the statement that "a random distribution is characterized by grouping". Any distribution (in this case, quartz in the groundmass) that displays grouping of data points is a random distribution rather than a regular distribution of some type.

APPENDIX 7

Quality Assessment of X-Ray Data

In this study, both the structural state analyses and composition analyses were graded according to the following conventions:

Composition Analyses:

For analyses with KBrO_3 internal standard (Orville, 1967), the spread (range) between maximum and minimum $\Delta 2\theta$ $[(\bar{2}01)$ feldspar - (101) KBrO_3] for each group of oscillations were assessed as follows:

Range		Data Quality
$^{\circ}2\theta$	% Or	
< 0.018	< 1.5	A
0.018 - 0.036	3.0	B
0.037 - 0.054	4.5	C
> 0.054	> 4.5	D

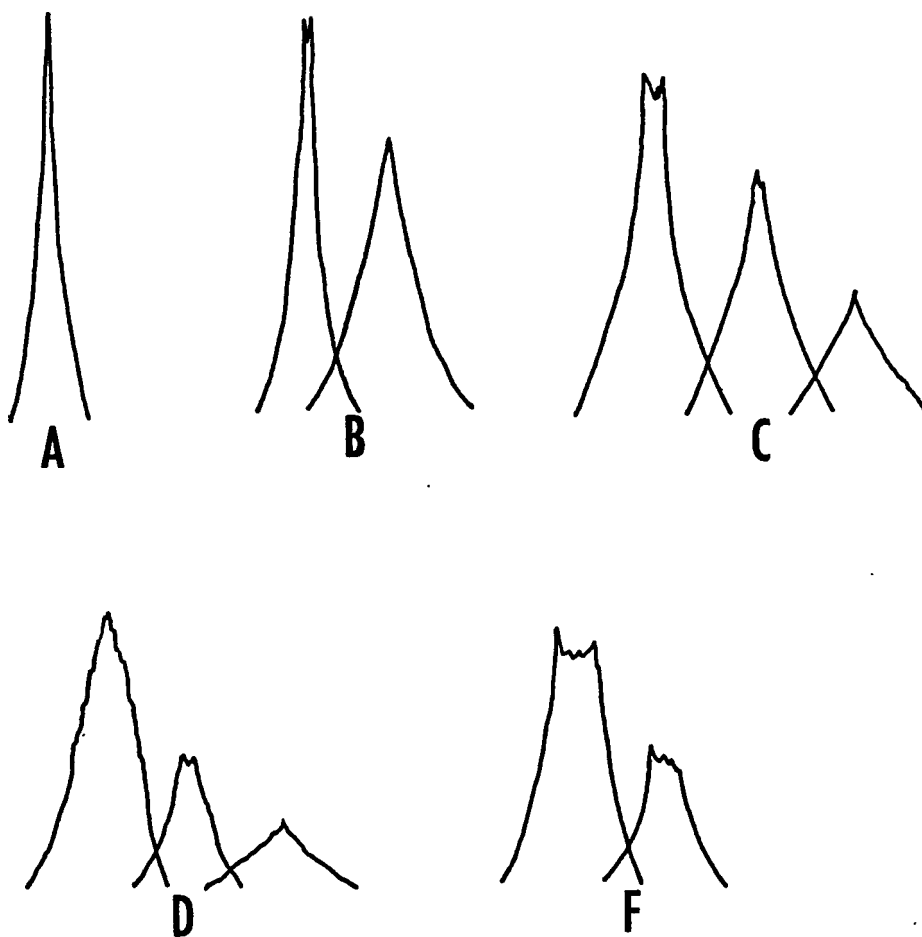
For analyses with Quartz internal standard (Tuttle and Bowen, 1958), the spread (range) between maximum and minimum $\Delta 2\theta$ $[(\bar{2}01)$ feldspar - $(10\bar{1}0)$ Quartz] for each group of oscillations were assessed as follows:

Range		Data Quality
$^{\circ}2\theta$	% Or	
> 0.017	> 1.5	A
0.017 - 0.034	3.0	B
0.034 - 0.050	4.5	C
< 0.050	< 4.5	D

Composition and Structural State Analyses:

In both analyses the peak shapes were graded (in effect the ability to unequivocally determine the center of the peak) using the following gross guides:

- a. height of peak
- b. width of peak
- c. sharpness of peak top, as shown below



For this work, C quality peaks or better were assumed to be essentially homogeneous; F quality peaks were assumed to be inhomogeneous.

APPENDIX 8

Modal Analyses

Techniques and methods used in point counting and calculation of the modal analyses present in this study are as recommended by Chayes (1956). The measurement and calculation of quartz present in these rocks was effected by a technique developed for this purpose (Appendix 6). The point counts were done on a Zeiss petrographic microscope utilizing a binocular headpiece at a magnification of 315x. The slide traversing stage was a Zeiss mechanical stage with 0.8 mm. vertical and 0.8 mm. horizontal step dimensions. A minimum of 1,000 points were counted for each analysis (voids or pores were not counted) and tabulated under one of the following headings:

1. Feldspar phenocrysts (feldspars longer than 0.3 mm. on the maximum diagonal).
2. Felsic groundmass (combined quartz and feldspars, since differentiation at this magnification was difficult or impossible).
3. Pyroxene phenocrysts (larger than 0.3 mm. on the major diagonal).
4. Pyroxene groundmass.
5. Iron oxide phenocrysts.
6. Iron oxide groundmass.
7. Others (each listed separately, generally, zircon, alteration products, unidentified grains, carbonate, etc.).

Modal analyses results are compiled in Table 1.

APPENDIX 9

Recommendations for Future Study

During the development of the objectives of this study, numerous corollary studies came to light. This writer intends to pursue most of these in the near future.

Studies Based on the Samples Presently Available:

1. Laboratory studies simulating contact metamorphic conditions on unaltered sedimentary rocks to produce the low-grade noted at the igneous contacts.
2. Additional optical work, specifically more 2V determinations, concentrated on the samples which show extremes in their range of composition and/or structural states.
3. Additional attempts at staining hypabyssal and alkali feldspars.
4. Attempts using phase contrast microscopy to differentiate extremely fine-grained quartz and feldspar such as in the groundmass of these samples.
5. Combined chemical and petrographic studies for portions of these masses, especially ferro-magnesian minerals, to attempt resolution of the pressure-temperature history.
6. Additional feldspar composition determinations using the method of Tuttle and Bowen so as to better compare their results with Orville's and the "three peak method".
7. Additional groundmass composition and structural state determinations for comparison with the phenocryst determinations of this study (see Figure 15).

8. Petrographic compositional and structural state analyses of dike samples to deduce their exact relationships with the main mass and the prongs.

9. Computer-refined structural state analyses of many of these samples to check both the approximate structural state as presented herein and to resolve the sanidine-anorthoclase problem. These refinements would also provide data which would be interesting to compare with the $\Delta \bar{201}$ values of this study.

10. Alkali exchange studies on these samples to attempt a refinement of Wright's composition diagram in the $Or_{30} - Or_{50}$ range.

11. Trend analyses of these and future data groups generated from this mass.

12. Microprobe analyses to establish the exact core-rim inter- and intra-grain per cent Or variations for the feldspars. Microprobe analyses might also allow determination of the pyroxene and amphiboles present as well as the very rare plagioclase grains.

13. The x-ray technique for determination of quartz needs further study and refinement before acceptance.

14. Additional chemical analyses, especially from the chilled zone of the main mass, might shed some light upon the amount and type of fractionization present in these rocks.

Studies Requiring New Samples or Additional Fieldwork:

1. Gravity, magnetic, resistivity, or seismic studies of this area could be performed with small portable instruments, and might clarify the relationships between the masses of the Mountain 4320 intrusion as well as neighboring complexes.

2. Contrast of potassium-argon age dating among (a) fresh phenocryst samples from the main mass, (b) detrital samples in the basin between the prongs, and (c) samples from the small lake at the south prong, may give some clue as to the effect of either subaerial exposure in an alkaline environment or deposition in a lacustrine environment on potassium-argon age dates.