A STUDY OF THE POTASSIUM FELDSPARS
IN SOME IGNEOUS AND METAMORPHIC ROCKS
FROM THE MOAK-THOMPSON MAP AREA, MANITOBA

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

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ABSTRACT

Sodium and potassium contents of 35 igneous and metamorphic rock specimens from the Moak-Thompson area were determined by flame photometer. Potassium feldspars were separated from the rocks and obliquities (triclinicities) of the minerals estimated from X-ray powder photographs. For a number of specimens an increase in obliquity may be correlated with an increase in the ratio K feldspar:total alkali feldspar with a monoclinic K feldspar occurring in a rock with ~ 23 mole % K feldspar of the total alkali feldspar and a maximum microcline in a rock with ~ 67 mole % K feldspar of the total alkali feldspar. It is suggested that there is a microcline series extending over the composition range ~ 23 - 67 mole % K feldspar of the alkali feldspar diagram, and a phase diagram is proposed.

A modification of the phase diagram for very high water pressures is proposed to account for the occurrence of microclines with a given obliquity in igneous rocks of differing alkali compositions. An orthoclase-low albite phase diagram is proposed to account for the orthoclase-cryptoperthite series.

Sodium and potassium contents and obliquities of 37 microclines were determined but no simple relationship was found between mineral composition and obliquity.

The study suggests a possible way of distinguishing between igneous and metamorphic rocks.

CHAPTER I

INTRODUCTION

Feldspars are the most abundant minerals in the earth's crust and thus are of particular importance to petrologists. Members of the feldspar group are closely related in form and physical properties. Laboratory studies have indicated that at high temperatures there is complete solid solution between K feldspar and Na feldspar and between Na feldspar and Ca feldspar and only limited solid solution between K feldspar and Ca feldspar. Thus the common rock forming feldspars are divided into two series, the plagioclase series (Na-Ca) and the alkali series (Na-K), the latter series being the one considered in this thesis.

In natural feldspars polymorphism and limited solubility of the low-temperature forms complicate the picture. K feldspar occurs in several polymorphic forms. Sanidine is a monoclinic high-temperature polymorph commonly found in volcanic rocks. Orthoclase, a second monoclinic variety, is found in igneous and metamorphic rocks as well as in pegmatites. Microcline, a triclinic polymorph is unusual in that the reciprocal lattice angles α^* and γ^* may range in value from 90° for a monoclinic member to $90^\circ 25'$ and $92^\circ 20'$ respectively. Microcline is a common K feldspar in igneous and metamorphic rocks and pegmatites. Adularia is the name given a morphologically monoclinic form with a distinctive crystal habit that is commonly found in low-temperature veins.

Two sodium feldspar polymorphs have been observed in natural specimens. High-temperature albite is found in volcanics and high-temperature veins. Low-temperature albite is the common Na feldspar in igneous and metamorphic rocks and pegmatites.

At low temperatures solid solutions intermediate between the potassium and sodium end members exsolve into an intergrowth of potassium- and sodium-rich solid solutions. These intergrowths are termed perthites if the K-rich solid solution predominates or anti-perthites if the Na-rich solid solution predominates.

Barth (1934) suggested that the potassium feldspar polymorphs differ by the degree of order or disorder of the Si and Al atoms, with low-temperature forms showing a high degree of ordering (Al concentrated in one site) and high-temperature forms showing a lesser degree of ordering.

Goldsmith and Laves (1954b) demonstrated that a maximum microcline heated at high temperatures undergoes a progressive change in lattice geometry from a maximum microcline through intermediate values of obliquity* to a monoclinic feldspar. They interpreted this as reflecting a change in the degree of Al-Si ordering with maximum microcline being fully ordered and monoclinic sanidine being disordered. They concluded that

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* "Obliquity" is used here in place of the more common "triclinicity" because the writer regards it as the more precise term. See Appendix 1.

obliquity is a function of temperature with maximum microcline the low-temperature form, intermediate microcline the intermediate-temperature form and monoclinic sanidine the high-temperature form. They suggested that "common orthoclase" consists of triclinic units twinned on a sub-X-ray scale to simulate monoclinic symmetry, and thus they do not regard it as a true polymorph.

Goldsmith and Laves (1954b) also showed that microcline heated under water pressure was changed to sanidine with no evidence of a progressive change in lattice geometry. They interpreted this as "a hydrothermal synthesis of sanidine, the microcline acting as source material".

In recent years a number of detailed structure analyses have been completed confirming the idea that the feldspar polymorphs differ by the degree of Al-Si ordering. In the Na feldspars, Ferguson et al (1958) found that in high albite the Al-Si atoms are disordered and in low albite most but not all of the Al is concentrated in one site. In the K feldspars, Cole et al (1949) found that monoclinic sanidine is completely disordered; Jones and Taylor (1961) found that monoclinic orthoclase is partially ordered; and Bailey and Taylor (1955) found an intermediate microcline (triclinic) to be partially ordered in a complex way. It is probable that maximum microcline is more highly ordered than the intermediate microcline (Goldsmith and Laves, 1954).

Although the structural evidence confirms the idea that the feldspar polymorphs are related by differences in degrees of ordering, Ferguson et al (1958) and Ferguson (1960), as a result of structural work, disagree with Goldsmith and Laves (1954b) that the low-temperature form of an alkali feldspar is the one most highly ordered with respect to Al-Si. Rather they suggest that the alkali feldspars behave as ionic compounds with the low-temperature forms having, in general, the Al-Si distribution that leads to the most satisfactory charge balance. In none of the alkali feldspars is this distribution likely a fully ordered one. By means of the ionic theory, the authors are able to offer explanations for the particular (not fully ordered) Al-Si distributions observed in low albite, intermediate microcline and orthoclase. Details of their theory are given in Ferguson et al (1958) and in Ferguson (1960).

MacKenzie (1954) suggested that the range of lattice parameters in the microcline series was due to the Na feldspar in solid solution in the K feldspar. Difficulty is encountered in testing this theory because chemical methods are unable to differentiate between Na feldspar in solid solution and Na feldspar exsolved as perthitic intergrowth.

Ferguson et al (1958) suggested that sodium is essential to the crystallization of mirocline, and that microcline forms as the result of exsolution of an alkali feldspar that contained appreciable sodium at higher temperatures. The K feldspar itself is the result of a more or less complete exsolution process, and thus it may not contain as much Na at low temperatures as it did before exsolution. The most highly triclinic potassium feldspar would be maximum microcline with the same Al-Si distribution as low albite, corresponding to a potassium feldspar crystallizing from a high sodium melt.

CHAPTER II

NATURE OF THE PRESENT STUDY

OBJECT OF THE STUDY

The aim of this study was to examine, for a series of rocks from one area, the possible relation of the obliquities ("triclinicities") of the K feldspars to:

i) the Na and K content of the potassium feldspars,
ii) the Na:K ratios in the respective rocks, and
iii) areal distribution and rock type.

DESCRIPTION OF ROCK TYPES

A suite of granitic rocks from the Moak-Thompson map area of Northern Manitoba was readily available for such a study as a fellow graduate student, J. M. Patterson, was studying the geology of the area for the Manitoba Government as well as for his own doctoral thesis. Detailed rock descriptions and a geological map are to be published in a Manitoba Department of Mines and Natural Resources' Report on the Moak-Thompson area by J. M. Patterson.

The specimens studied have been divided into five groups according to rock type by the Manitoba Mines Branch.

Red Granite

In outcrop this unit is massive to slightly foliated, medium to coarse grained, and locally porphyritic. Typical specimens are composed of red perthitic microcline (50%), sodic plagioclase An_{20-25} (20%), quartz (25%), and biotite (5%). The plagioclase is commonly sericitized. Minor amounts of muscovite, apatite, zircon and iron oxides are present in some rocks.

Grey Granodiorite

This rock is massive to foliated. The average specimen contains plagioclase (60%), quartz (25%), potassium feldspar (15% or less but locally up to 30%), and biotite (5%). The relationship of this unit to the granite gneiss and red granite is not known.

Granite Gneiss

In general this is a well foliated to moderately well banded grey, white or pink rock. It is intruded by the red granite. Many of the contacts with adjacent sedimentary gneiss and granitic rocks are gradational. In some areas a mixture of granite gneiss, sedimentary gneiss and granitized gneiss are included in this unit. Basic inclusions and basic bands are common.

This unit includes a wide range of compositions. The major minerals are plagioclase An_{20-25} (40-60%), potassium feldspar (0-40%), quartz (25-40%), and biotite (0-10%). Plagioclase is commonly highly seri~~t~~ci~~c~~tized in the specimens with a high alkali content, or altered to epidote in the more basic rocks. Apatite, zircon, sphene and iron oxides are common accessories.

Sedimentary Gneiss

This unit is characterized by fine persistent banding. Locally broad bands (or sills) of amphibolite and/or pegmatites accentuate this fine banding.

The important minerals in these rocks are plagioclase (40-60%), quartz (20-40%), and biotite (0-15%) with potassium feldspar locally making up 50% of the rock. Garnet and amphibole are important in some zones. Chief accessories are apatite, zircon, iron oxide and sphene. Pyroxene, sillimanite, cordierite, staurolite and kyanite are found in many of the rocks. Plagioclase is commonly sericitized in the rocks high in alkali or altered to epidote in the more basic rocks, and either of these conditions made it impossible to obtain reliable compositions of the original plagioclase by the usual optical methods.

Pyroxene Granulite or Charnockite

The charnockites are well foliated to poorly banded rocks. A wide range of compositions is included in this unit. Plagioclase An_{30-40} (30-50%), quartz (30-50%), and potassium feldspar usually less than 15% but in places up to 30%. Coarse perthite and antiperthite are common. Locally pyroxene constitutes 30% of the rock but averages 5%. Hypersthene is the common pyroxene although both hypersthene and clinopyroxene are found in some specimens. Combinations of biotite, chlorite, amphibole, magnetite, antigorite and serpentine are pseudomorphs after pyroxene.

In studying the natural feldspar system it is desirable to consider both the alkali and the plagioclase feldspars. Calcium contents of the rocks should have been determined in addition to the alkalies, but no ready method of determination was available. As optical studies indicate that Ca is present in the plagioclases, it is necessary to regard the system as a pseudobinary join between K feldspar and a sodic plagioclase.

EXPERIMENTAL TECHNIQUES

The potassium feldspars were separated from the rocks by standard heavy liquid procedures. Sodium and potassium contents of both the potassium feldspar and the rock specimens were determined with a flame photometer. Obliquities (triclinicities) were determined from X-ray powder photographs of the K feldspar specimens taken with 114.53 mm cameras. The alkali compositions of the feldspars were determined with a Philips diffractometer using the $(\bar{2}01)$ spacing on the powder patterns (Bowen and Tuttle, 1950; Orville, 1957). Details of experimental techniques are given in Appendix 1.

CHAPTER III

EXPERIMENTAL RESULTS OF THE PRESENT STUDY

RELATION OF OBLIQUITIES TO Na:K RATIOS IN THE K FELDSPARS

Thirty-seven K feldspars were selected for chemical analysis in an attempt to establish any possible relationship between alkali ratio and obliquity. Powder photographs were taken of these samples before analysis. The strongest line of albite (a combination of the 002, 040, 220 and $2\bar{2}0$ reflections) was visible on nearly all of the patterns indicating that these specimens contained appreciable exsolved albite. The samples were selected to include the whole range of obliquities. Intermediate values (obliquity = 0.4 - 0.5) were rare. It was difficult to obtain samples with low obliquities in a pure form because such grains are highly irregular in outline (best described as interstitial), and they only make up small percentages of the rocks in which they occur.

Compositions were determined with a flame photometer. As a check on the flame photometer determinations, the potassium-sodium contents of the feldspars were estimated by the $\bar{2}01$ method (Bowen and Tuttle, 1950; Orville, 1957). For this purpose the specimens were first heated at 1050°C for 140 hours.

Results of the analyses by both the flame photometer and the $\bar{2}01$ methods, and the obliquities, are given in Table 1. For 19 of the specimens the K feldspar contents determined by the $\bar{2}01$ method are within 4 mole % of the flame photometer values. For ten specimens the two methods yielded results differing by

5-10 mole % K feldspar. In general the diffractometer results indicate higher K feldspar contents suggesting that these specimens were not completely homogenized by the heat treatment.

The potassium contents in mole % of the K feldspars (using the flame photometer values) are plotted versus obliquities in Figure 1. If there is a simple relationship between obliquities and the alkali compositions of the K feldspars, it is not evident in this suite of minerals. It is evident that a K feldspar with a given obliquity may have a range in compositions. Whether the sodium is present in solid solution within the potassium feldspar or as a separate phase cannot be determined by chemical analysis. As noted above the X-ray powder photographs indicate that at least part of the sodium is present as a separate albite phase in most of the specimens.

RELATION OF OBLIQUITIES TO Na:K RATIOS IN THE ROCKS

The obliquities of the K feldspars and the potassium-sodium contents (determined by flame photometer) of the rocks are listed in Table 2. Sodium and potassium have been recalculated to mole % feldspar of the total alkali feldspar. The data given in Table 2 and plotted in Figure 2 show that for a large number of specimens there is an increase in obliquity corresponding to an increase in the ratio K feldspar:total alkali feldspar of the rock.

In interpreting this diagram it must be remembered that the obliquities are measurable within ± 0.05 under the most favourable condition (obliquities greater than 0.4). In the

TABLE I

CHEMICAL COMPOSITIONS AND OBLIQUITIES OF MICROCLINES

			Flame Photometer			Diffractometer ($\bar{2}01$ method)
Specimen Number	Rock Type*	Obliquity	K_2O (wt.%)	Na_2O (wt.%)	K feldspar (mole %)	K feldspar (mole %)
M-113-58	GG	0.77	13.58	1.75	83.6	-
M-336-58	GG	0.81	-	-	-	84.9
M-361-58	GG	0.96	-	-	-	86.6
P-364-58	PG	0.79	-	-	-	77.5
P-511-58	PG	0.50	13.54	1.84	82.9	87.0
P-588-58	PG	[0.70 0.00]	13.57	1.83	83.0	85.3
P-621-58	PG	0.00	13.48	2.13	80.6	-
A-1-3-59	RG	0.90	14.44	1.34	87.6	89.0
A-4-1-59	GG	0.00	10.81	2.88	71.2	-
A-6-59	GG	0.35	11.43	2.43	75.6	-
A-7-59	GG	0.35	12.93	3.19	72.7	-
A-8-59	RG	0.80	9.94	2.74	70.5	-
A-11-59	RG	0.96	14.11	1.94	82.7	85.7
A-20-59	RG	0.87	-	-	-	99.8
A-32-59	RG	0.82	-	-	-	87.0
A-55-2-59	GG	0.87	-	-	-	90.7
A-57-59	GG	0.72	15.06	1.09	90.1	96.5
A-65-59	GG	0.65	11.30	1.48	83.4	-
A-110-59	RG	0.96	14.88	1.23	88.8	90.7
A-173-59	RG	0.81	14.04	1.58	85.4	90.7
A-276-59	GG	0.86	-	-	-	88.2

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* Abbreviations for rock types.

RG - Red granite
GGd - Grey granodiorite
GG - Granite gneiss
SG - Sedimentary gneiss
PG - Pyroxene granulite

TABLE I cont'd.

CHEMICAL COMPOSITIONS AND OBLIQUITIES OF MICROCLINES

Specimen Number	Rock Type*	Obliquity	Flame Photometer K_2O (wt.%)	Flame Photometer Na_2O (wt.%)	Flame Photometer K feldspar (mole %)	Diffractometer ($\bar{2}01$ method) K feldspar (mole %)
A-356-59	GG	0.20	11.70	1.38	84.8	-
A-445-59	SG	0.64	13.45	1.68	84.0	80.0
A-468-59	GGd	0.89	-	-	-	80.8
A-490-59	SG	0.10	12.10	1.33	85.7	-
A-548-59	SG	0.30	13.86	1.25	87.9	93.2
A-635-1-59	SG	0.81	-	-	-	91.1
A-682-59	SG	0.87	14.15	1.36	87.2	90.3
A-807-59	SG	0.61	14.43	1.22	88.6	92.8
B-48-1-59	GG	0.74	13.38	1.74	83.5	88.2
B-84-3-59	GG	0.85	13.48	1.50	85.5	90.3
B-87-1-59	RG	0.86	10.12	3.80	63.7	71.8
B-113-1-59	RG	0.59	13.70	1.42	86.4	82.4
B-184-59	RG	0.89	14.45	1.48	86.5	86.5
B-233-59	GG	0.20	14.45	1.73	84.6	83.2
B-338-59	GG	0.69	13.60	1.57	85.1	83.2
B-370-59	RG	0.86	14.13	1.46	86.4	95.7
B-403-1-59	SG	0.00	12.26	1.97	80.4	89.9
B-448-1-59	GGd	0.81	13.93	1.32	87.4	90.7
B-459-59	GG	0.69	13.32	1.63	84.3	86.6
B-465-59	GG	0.90	13.61	1.93	82.3	82.4
B-591-59	GG	0.87	-	-	-	82.2
B-692-59	SG	0.98	14.95	1.13	89.7	89.9
B-701-59	SG	0.90	13.55	1.82	83.4	90.7
B-768-59	GG	0.86	-	-	-	86.1
C-103-59	RG	0.80	10.92	3.71	65.9	82.4
C-179-1-59	GGd	0.85	14.25	2.14	81.4	91.1
C-288-4-59	SG	0.30	-	-	-	85.7
C-506-59	SG	0.51	14.55	1.51	86.4	99.9

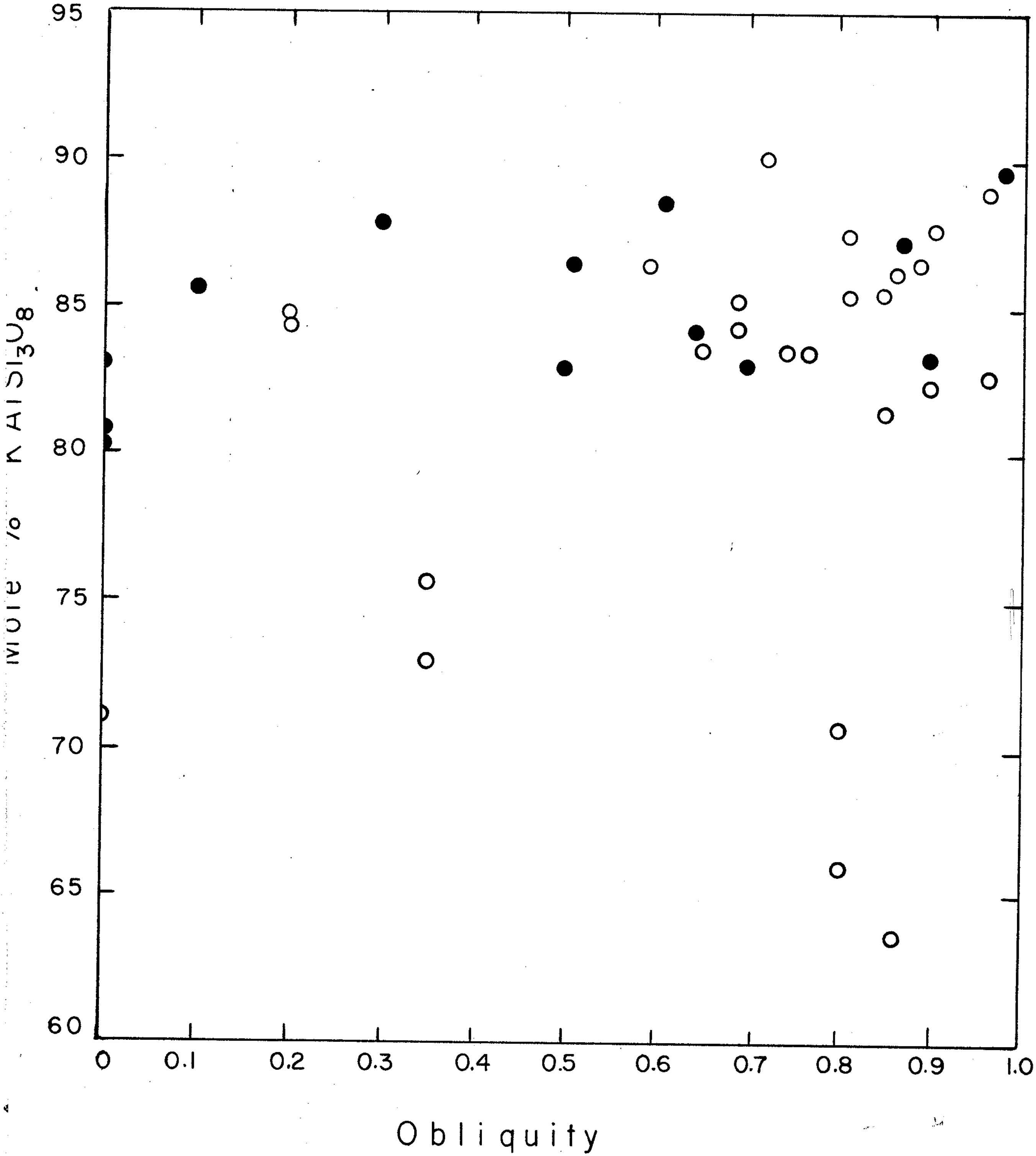

Figure 1. Plot of obliquity versus mole % $KAlSi_3O_8$ to total alkali feldspar in the K feldspar specimens. Open circles denote rocks of probable igneous origin. Closed circles denote rocks of probable metamorphic origin.

TABLE II

ALKALI CONTENTS OF ROCKS AND OBLIQUITIES OF K FELDSPARS

Chemical Compositions by Flame Photometer

Specimen Number	Rock Type*	Obliquity	K_2O (wt.%)	Na_2O (wt.%)	K feldspar mole %	$\frac{\text{Moles } Na_2O}{\text{Moles } K_2O}$
M-113-58	GG	0.77	4.28	4.25	39.9	1.51
P-324-58	PG	0.10	2.47	3.84	29.7	2.36
P-340-58	PG	0.25	1.37	3.48	20.6	3.86
P-511-58	PG	0.50	5.89	3.96	49.6	1.03
P-588-58	PG	[0.70 0.00]	4.41	3.06	48.9	1.05
P-621-58	PG	0.00	1.91	4.54	21.7	3.61
A-4-1-59	GG	0.00	4.18	3.57	43.5	1.30
A-6-59	GG	0.35	1.80	6.06	16.4	5.12
A-7-59	GG	0.35	3.96	4.77	35.3	1.83
A-8-59	RG	0.80	3.85	5.07	33.3	2.00
A-11-59	RG	0.96	7.13	3.46	57.6	.74
A-57-59	GG	0.72	3.84	4.97	33.7	1.97
A-61-59	SG	0.10	2.17	4.11	25.8	2.88
A-65-59	GG	0.65	2.95	4.76	29.0	2.45
A-110-59	RG	0.96	4.02	4.82	35.4	1.82
A-173-59	RG	0.81	8.43	3.60	60.6	.65
A-356-59	GG	0.20	2.56	3.63	31.7	2.15
A-445-59	SG	0.64	4.76	3.81	46.5	1.15
A-490-59	SG	0.10	2.92	4.52	29.8	2.35
A-548-59	SG	0.30	3.72	4.27	36.4	1.74

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* Abbreviations for rock types.

RG - Red granite

GGd - Grey granodiorite

GG - Granite gneiss

SG - Sedimentary gneiss

PG - Pyroxene granulite

TABLE II cont'd.

ALKALI CONTENTS OF ROCKS AND OBLIQUITIES OF K FELDSPARS

Chemical Compositions by Flame Photometer

Specimen Number	Rock Type*	Obliquity	K_2O (wt.%)	Na_2O (wt.%)	K feldspar mole %	$\frac{\text{Moles } Na_2O}{\text{Moles } K_2O}$
A-682-59	SG	0.87	6.38	3.21	56.7	.76
A-807-59	SG	0.61	5.90	3.45	53.0	.89
B-48-1-59	GG	0.74	4.00	4.38	37.5	1.66
B-113-1-59	RG	0.59	3.96	4.86	34.9	1.86
B-233-59	GG	0.20	3.11	4.73	30.3	2.31
B-338-59	GG	0.69	4.71	3.63	46.1	1.17
B-403-1-59	SG	0.00	1.79	3.90	23.2	3.31
B-448-1-59	GGd	0.81	5.28	2.95	54.1	.85
B-459-59	GG	0.69	1.71	5.76	16.3	5.12
B-465-59	GG	0.90	6.39	2.64	61.4	.63
B-692-59	GG	0.98	6.00	2.65	59.8	.67
B-701-59	SG	0.90	6.23	2.24	64.7	.55
C-103-59	RG	0.80	3.47	5.24	30.4	2.29
C-179-1-59	GGd	0.85	3.96	4.56	36.4	1.75
C-506-59	SG	0.51	6.07	4.12	49.2	1.03

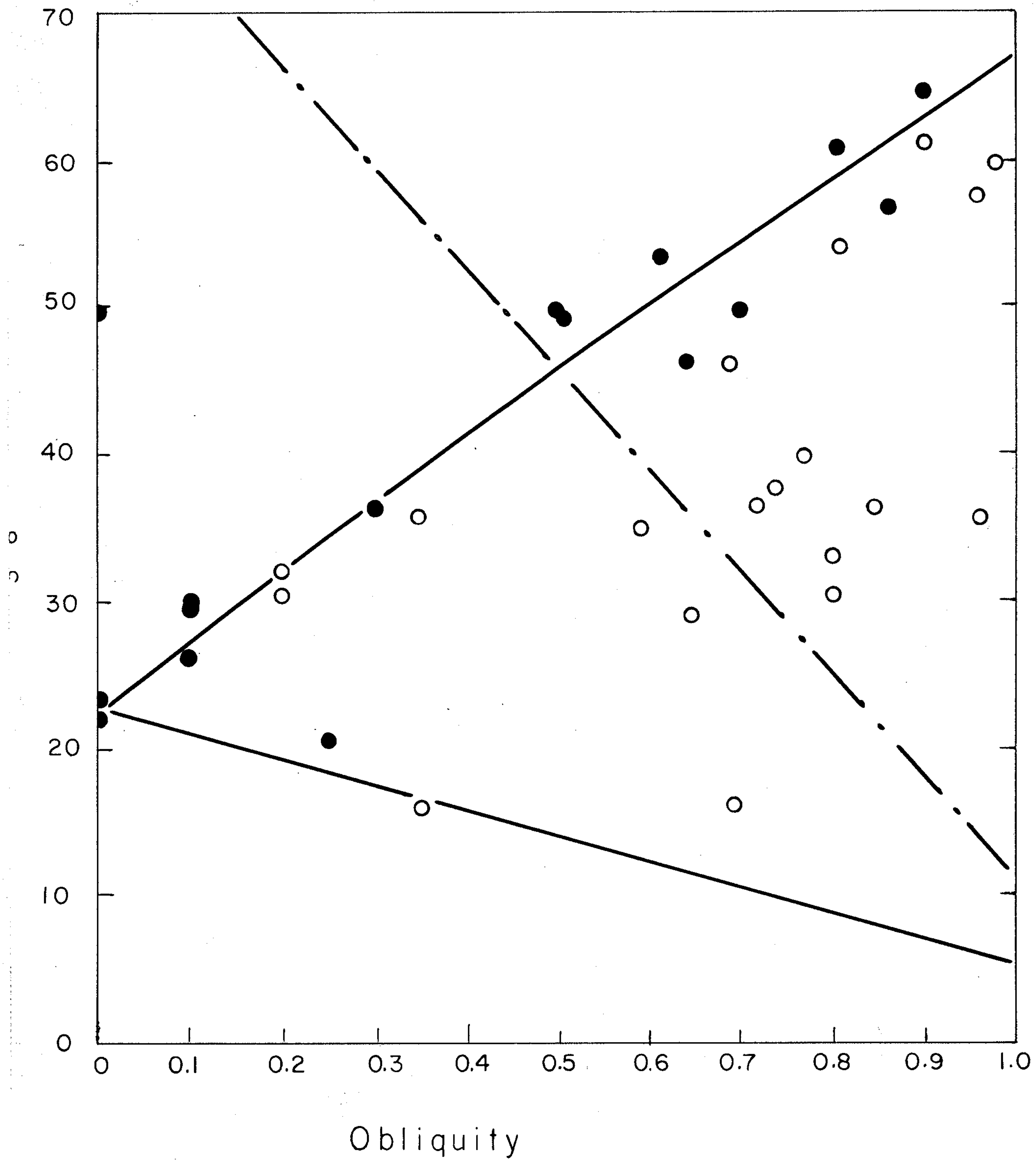

Figure 2. Plot of obliquity versus mole % KAlSi$_3$O$_8$ to total alkali feldspar in the rock specimens. Significance of the solid and chained lines is discussed in the text.

Open circles denote rocks of probable igneous origin.

Closed circles denote rocks of probable metamorphic origin.

case of lower obliquities the values given are estimates of line widths, and they may be less accurate although the relative values are probably significant.

If a nearly straight line is drawn from 22 mole % K feldspar for a monoclinic feldspar (obliquity = 0) to 67 mole % K feldspar at the maximum microcline side (obliquity = 1) a large number of the points fall close to the line. All rock types (including some of probable igneous origin) included in this study are represented by these points. Removed from, but mainly below, this line there is a scattered group of points representing rocks of probable igneous origin. A discussion of possible reasons for the obliquities of this group not being simply related to the compositions will be given after consideration of a possible alkali feldspar phase diagram.

Figure 2 shows that in some rocks the obliquity of the K feldspar may be correlated to the total alkali composition. In general an increase in obliquity may be correlated with an increase in potassium content. If we consider a given composition, for example 35 mole % K feldspar, Figure 2 indicates that the K feldspar may have an obliquity equal to or greater than 0.3. Thus the line drawn may represent the <u>minimum</u> obliquity that a K feldspar may possess if it crystallizes and cools to ordinary temperatures at or near equilibrium conditions assuming that obliquity is, in some way, determined by the total alkali in the rock.

This does not mean that it is impossible to have K feldspars that would plot above the line. The heating experiments of Goldsmith and Laves (1954b) showed that if a specimen is strongly heated the obliquity can be reduced. However it should be pointed out that these heating experiments were carried out on fairly pure K feldspars that have been removed from the alkali feldspar system of which they are a part. If a microcline in a rock were heated after the Na feldspar had exsolved out (into separate grains) the obliquity would be reduced. The resulting K feldspar would have an obliquity which was not related to the total alkali content of the rock.

Specimen P-588-58 (48.7 mole % K feldspar) was found to contain two K feldspar phases -- a microcline with obliquity = 0.70 and a monoclinic phase. This is interpreted as a partial change of the microcline to a monoclinic feldspar. Water was probably present during the transition for the original pyroxene in the rock has been replaced by a number of hydrous minerals. The reaction was probably similar to that carried out by Goldsmith and Laves (1954b) in their hydrothermal-treatment of microcline. In order to obtain obliquities intermediate between the original value and the monoclinic member the K feldspar would have to be heated in a dry environment.

Table 2 and Figure 2 also suggest that in alkali feldspar systems containing less than 23 mole % K feldspar the K feldspar will form a microcline. Only three specimens were found which contain less than 23 mole % K feldspar, and these are all intermediate microclines. This is very little evidence to offer in support of a second microcline series but such a series may exist.