THE GEOLOGY AND GEOCHEMISTRY OF TIN AND BERYLLIUM MINERALISATION IN SOUTH WEST ANKOLE, UGANDA

by

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ABSTRACT

A study has been made of tin and beryllium mineralisation in South-West Ankole, including beryl-bearing granite pegmatites, quartz-mica cassiterite-bearing veins and hydrothermal quartz cassiterite-bearing veins. The mineralisation belongs to one of several tectono-metallogenic provinces which occur along the Kibaran orogenic belt, and the mineral deposits of S.W. Ankole are situated at the northern end of this belt. The mineral deposits are shown to occur in the exo- and endo-contact zones of updomed pre- syn- and late-tectonic 'arena' granites which were emplaced during the Kibaran orogeny, and the mineralisation which post-dates emplacement of the granitic rocks, is shown to exhibit marked regional zoning with respect to the granite boundaries.

The nature, mode of occurrence, time of formation and relationship of the mineral deposits to each other and to the granitic and metasedimentary rocks of S.W. Ankole are described and the granite pegmatites in particular are classified and placed into a conventional classification scheme.

The results of a geochemical study of the mineralisation are presented and show the distribution of tin and beryllium in all the main rock types of S.W. Ankole. The geological and geochemical data are applied to prove that that mineral deposits are epigenetic in origin and were formed as a result of post-tectonic magmatic and hydrothermal processes which operated at the end of the Kibaran orogeny. Details of the mode of occurrence, and distribution of tin in tin-bearing rocks and minerals are presented and hypotheses are advanced to explain the mechanisms of transport and concentration of tin and beryllium during formation of the mineral deposits. It is established that the tin and beryllium were probably derived from

pre-existing granitic rocks containing average crustal abundances of these elements, and that concentration occurred as a result of the magmatic and hydrothermal processes that operated at the end of the Kibaran Orogeny. Transport of tin is suggested to have been in the form of alkali-hydroxy-fluo-stannate complexes.

Data on the alkali, fluorine and tin content of muscovites from all the mineral deposits are presented, and it is shown that muscovites from the hydrothermal quartz-cassiterite-bearing veins can be distinguished from those from the other mineral deposit types on their alkali and tin contents and the use of muscovite as a prospecting indicator in searching for new hydrothermal tin deposits (in S.W. Ankole) is advocated.

CONTENTS

SECTION II

THE GEOCHEMISTRY OF THE TIN AND BERYLLIUM MINERALISATION

SECTION III

APPENDICES

APPENDIX II. ANALYTICAL DATA

II.a. TIN AND BERYLLIUM CONTENTS OF GEOCHEMICAL (ROCK) SAMPLES FROM S.W. ANKOLE

IIb. PARTIAL ANALYSES OF MICAS FOR ALKALIS, FLUORINE AND TIN

LIST OF ENCLOSURES (IN POCKET)

Enclosure No.

INTRODUCTION

Location and Accessibility

South-West Ankole is situated in the south-western part of the Republic of Uganda (see fig. 1), and is bordered on its western side by Kigezii District and on its southern side by Rwanda and Tanzania. There are no towns, but small trading centres occur at Ntungamo, Rwashamaire, Rwentobo, Kafunzo and Kikagati. The nearest town is Mbarara, the administrative centre of Ankole, which is situated about 50 miles to the north-east of Ntungamo and about 180 miles to the south-west of Kampala (the capital city of Uganda). Ntungamo is linked to Mbarara and Kampala by a good tarmacadam road which has recently been extended 50 miles to the south-west to serve Kabale in Kigezii.

Physiography

Most of South-West Ankole lies at an elevation of between 4,500 and 6,000 feet above sea level and the topography of the area is strongly controlled by the geology.

Areas underlain by granitic rocks occupy the lower ground, and are surrounded by higher hills formed of metasedimentary rocks. As many of the outcrops of granitic rock are circular or subcircular in outline, the depressions they occupy have been termed 'arenas' (A.D. Combe 1932).

The topography is generally well rounded, although steep scarp slopes have developed on the inward facing sides of the hills which encircle the arenas.

The rainfall of S.W. Ankole is low, being confined to two relatively short rainy seasons from February to April and September to October; during the dry seasons the climate is semi-arid (see plates 1 and 2).

PLATE 1.

S.W. Ankole in the rainy season.

View south along the western wall of the Ntungamo Arena.

PLATE 2.

S.W. Ankole in the dry season.

View west towards the head of the Katuba Valley from Rwabaramira Hill.

There are no permanently flowing rivers, and the natural vegetation is restricted to short grass on the hills and papyrus swamps in the valleys and flat low-lying areas. The papyrus swamps have been formed as a result of reversed drainage caused by warping of the land surface due to recent movements associated with the Western Rift Valley. Lake Karenge (to the south of Rwashamaire) has been formed from waters trapped as a result of the drainage reversal.

Geology

The geology of S.W. Ankole has been well known since the area was first mapped and described by A.D. Combe in 1932. Since that time the area has received the attention of several other workers who have concentrated on various aspects of the geology (see table 1). The area has also been remapped by the Uganda geological Survey and the results have been published on the Bushenyi (85) and Rwentobo (94) (1:100,000) sheets in 1963 and 1965 respectively.

A more detailed geological map of a part of S.W. Ankole which contains additional information collected by the writer has been compiled, (see enclosure 1) and is based both on A.D. Combe's 1932 maps and on the recent Bushenyi and Rwentobo sheets.

The rocks of S.W. Ankole can be divided into two broad units:-

1. The Karagwe Ankolean System - a succession of metasedimentary rocks consisting of schists and phyllites with numerous quartzites and occasional masses of calc-silicate rock, which overlies,
2. Granitic Rocks, which include pegmatitic granites, porphyroblastic biotite granites, granodiorites, streaky porphyroblastic gneisses, banded gneisses, and injection schists which may belong to the Toro System.

Table 1 .

Titles of selected literature on the Geology of South West Ankole

Subject Heading	Title	Author	Date
General geology	The Geology of South West Ankole and Adjacent Territories with special reference to the Tin Deposits	A.D. Combe	1932
"	The Geology of Southwestern Uganda, with special reference to the Stanniferous Deposits	H.A.Stheeman	1932
Structure	The structure and metamorphism of the Mantling Karagwe-Ankolean sediments of the Ntungamo gneiss dome and their time-relation to the development of the dome	R.Nicholson	1965
Structure, metamorphism and granites	The mode of emplacement of the Post-Karagwe-Ankolean Granites of S.W. Uganda	B. C. King	1947
"	Problems of the Pre-Cambrian of central and western Uganda - Part 1. Problems of Correlation, and Part 2. Structure, metamorphism and granites	"	1959
"	Pre-cambrian structure and origin of the granitic rocks of S.W. Uganda	J.W. Barnes	1956
Geochronology	The Kibaran-Burundian - Karagwe Ankolean Belt	L. Cahen & N.J. Snelling	1966

Widespread tin and beryllium mineralisation has occurred in S.W. Ankole, and mineral deposits occur associated with the granitic rocks which include beryl-columbite-tantalite bearing granite pegmatites, quartz-mica cassiterite-bearing veins, and hydrothermal quartz cassiterite-bearing veins.

The Karagwe-Ankolean System

The Karagwe-Ankolean System consists of a folded and metamorphosed succession of arenites and argillites over 26,000 feet in thickness which contains numerous quartzites interbedded with cleaved mudstones, slates, phyllites and schists. Quartzite conglomerates occur sporadically and siliceous limestones now represented by calc-silicate rocks are found at the base of the succession.

Stratigraphy

The stratigraphy of the K-A System in S.W. Uganda has been well known since it was first described in detail by A.D. Combe (1932). Since that time several other attempts have been made to elucidate the stratigraphy of the Karagwe Ankolean System both in Uganda, and in the adjacent territories of Rwanda and Tanzania, and a correllation of the successions obtained is presented in table 2.

The successions are basically similar but differ in the positions of the boundaries between the Lower, Middle and Upper Divisions; disagreement also arises as to the position and nature of the basal unconformity.

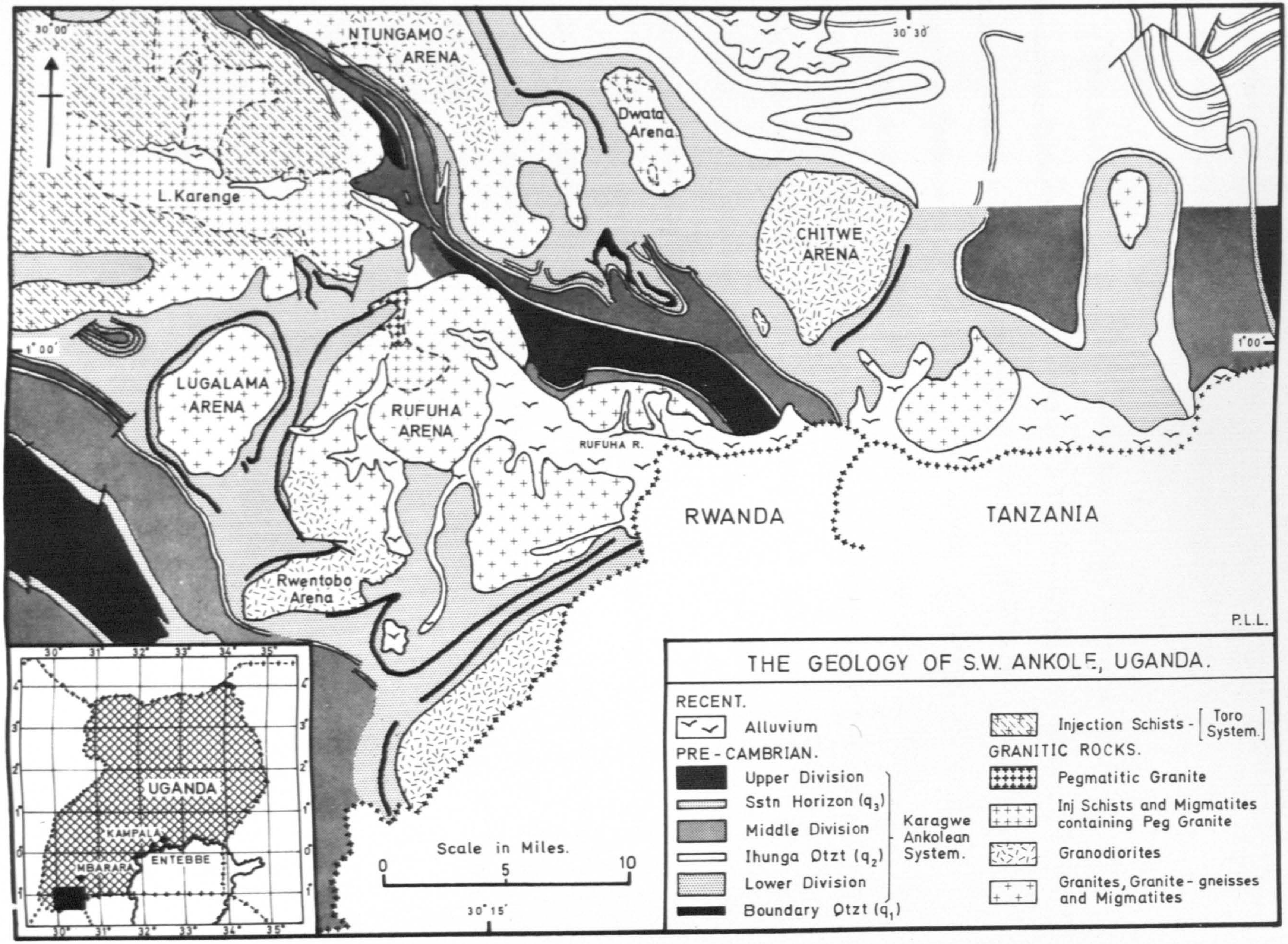
The writer considers that the rocks of the Karagwe-Ankolean System may unconformably overlie rocks of the Igara Series which belong to the Toro System, and in this thesis the following stratigraphic

Table 2.

CORRELATION OF THE STRATIGRAPHY OF THE K-A SYSTEM IN UGANDA AND ADJACENT TERRITORIES.

SOUTH - WEST UGANDA.					N.W. TANZANIA.	N.E. RWANDA.
South-West Ankole			Buhwezu Area	Ntungamo Area	Karagwe Tinfields	
A.D. COMBE. 1933.	H.A. STHEEMAN. 1932	J.W. BARNES. 1956.	A.W. REECE. 1961.	R. NICHOLSON. 1965.	STOCKLEY & WILLIAMS. '38	CAHEN & LEPERSONNE. 1966
UPPER DIVISION.	UPPER DIVISION. *Phyllitic and sandy micaceous shales.*	UPPER DIVISION.				MIYOVE SERIES. BYUMBA SERIES.
q6	MIDDLE DIVISION.	q6			KISHANDA BEDS	*LUKIRI QTZT* - QL *Phyllites*
Mudstones, shales and phyllites with quartzites. q5	Sstn Horizon	*Argillaceous rocks with sstns, grits and conglomerates.* q5		KARABOGOTA SERIES		*U. RWAMABARE QTZT* - QR3 *Phyllites*
q4	*Quartzites and micaceous sstns.*	q4			MTAGATA 'QUARTZITE'	*M. RWAMABARE QTZT* - QR2 *Phyllites*
q3		MIDDLE DIVISION. *SSTN HORIZON* - q3	BUHWEZU GROUP. *MUNYONI QTZTS*			*L. RWAMABARE QTZT* - QR1
MIDDLE DIVISION. *Shales and phyllitic shales.*	*Phyllites and sandy micaceous shales*	*Mudstones, shales, phyllites, sstns and conglomerates.*	*KASYOHA SHALES*	AKARUNDI SERIES	MBIRA BEDS	LOWER SERIES. *Phyllites* *MULINDI QTZT* QM *Phyllites*
LOWER DIVISION. q2	LOWER DIVISION. *IHUNGA QTZT*	LOWER DIVISION. *IHUNGA QTZT* - q2	*LUBARE QTZT*		*KAFULU QTZT*	*NDUBA QTZT* - QN
Shales, phyllitic shales, phyllites, and mica schists q2a	*Garnet phyllites* *GARNET QTZT* *U. Sericite Phyllites*	*Phyllites and sericite schists with quartzites* q2a		NTOMA SERIES	THE ARENA BEDS	*Phyllites, quartz-phyllites and qtzts*
with quartzites. - q1	*BOUNDARY QTZT* *L. Sericite Phyllites*	*BOUNDARY QTZT* - q1 IGARA SERIES. *Phyllites, schists, qtzt and diopside rocks.*	*ISINGIRO CONGL' LUKIRI MUDSTONES*		No base exposed in Karagwe	
q1a		'BASEMENT'	IGARA GROUP (TORO SYSTEM). *METAMORPHIC COMPLEX*			
Intrusive contact with Granites	Intrusive contact with Granites					

Fig 1


30°00′
30°30′
1°00′
1°00′
30°15′
NTUNGAMO ARENA
Dwata Arena
L. Karenge
CHITWE ARENA
LUGALAMA ARENA
RUFUHA ARENA
Rwentobo Arena
RUFUHA R.
RWANDA
TANZANIA
UGANDA
KAMPALA
ENTEBBE
MBARARA
Scale in Miles.
0
5
10
P.L.L.
THE GEOLOGY OF S.W. ANKOLE, UGANDA.
RECENT.
Alluvium
PRE-CAMBRIAN.
Upper Division
Sstn Horizon (q_3)
Middle Division
Ihunga Qtzt (q_2)
Lower Division
Boundary Qtzt (q_1)
Karagwe Ankolean System.
Injection Schists - [Toro System.]
GRANITIC ROCKS.
Pegmatitic Granite
Inj Schists and Migmatites containing Peg Granite
Granodiorites
Granites, Granite-gneisses and Migmatites

succession will be adopted for the sedimentary rocks of S.W. Ankole. (Table 2A) A map showing the general geology of S.W. Ankole and the distribution of the major divisions in the K-A system appears opposite (fig. 1).

Structure

The K-A rocks of S.W. Uganda occur at the N.E. end of the Kibaran-Burundian-Karagwe-Ankolean orogenic belt, in which sedimentary rocks with a predominantly N.E. strike can be followed practically continuously from the Katanga-Angola border in the south, to Uganda in the North.

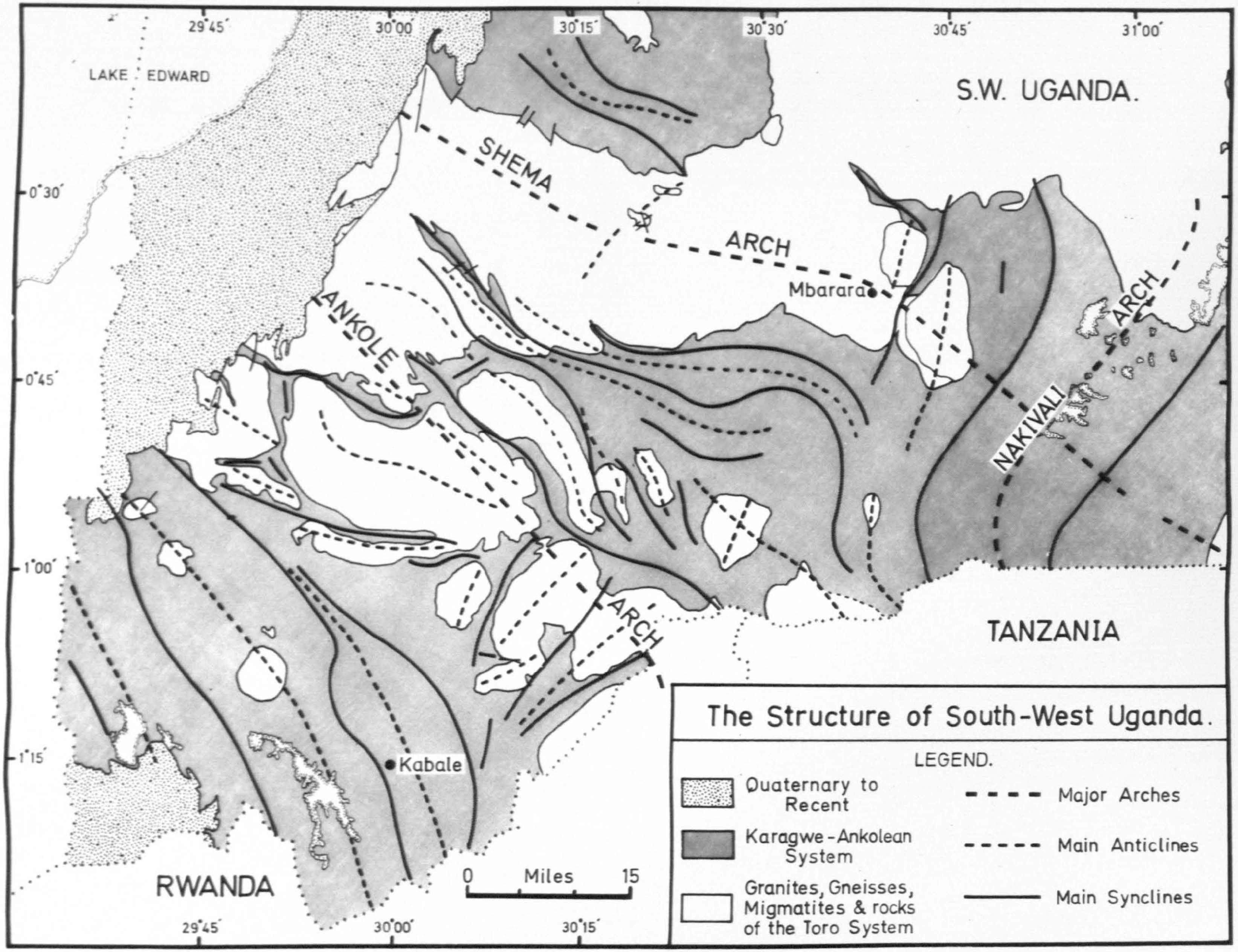
The rocks of the K-A System have been subjected to folding, which in S.W. Uganda has produced anticlinorial structures (arches), synclinoria, regional folds, cross folds, domes and minor folds (Barnes 1956). An outline of the major structures in the Karagwe-Ankolean rocks of S.W. Ankole is shown in fig. 2 .

Cleavage resulting from two phases of deformation have been recognised (Nicholson 1965) i.e: early regional schistosity and late formed crenulation cleavage resulting from close puckering of early cleavage. The late formed cleavage is restricted to areas of dome formation.

Metamorphism

The Karagwe-Ankolean System has been regionally metamorphosed to varying degrees with low grade epizonal metamorphism occurring in the synclinorial portions and higher grade mesozonal metamorphism in the anticlinoria (arches) where emplacement of granitic rocks has taken place. Metamorphism has resulted in the conversion of argillites to slates, phyllites and schists, recrystallisation of arenites (ortho-quartzites to form para-quartzites), and the formation of calc-silicate rocks from original impure calcareous rocks.

Fig 2



29°45′
30°00′
30°15′
30°30′
30°45′
31°00′
0°30′
0°45′
1°00′
1°15′
LAKE EDWARD
S.W. UGANDA.
SHEMA
ARCH
ANKOLE
Mbarara
NAKIVALI
ARCH
ARCH
TANZANIA
RWANDA
Kabale
0
Miles
15
The Structure of South-West Uganda.
LEGEND.
Quaternary to Recent
Karagwe-Ankolean System
Granites, Gneisses, Migmatites & rocks of the Toro System
Major Arches
Main Anticlines
Main Synclines

Table 2a

STRATIGRAPHIC SUCCESSION - S.W. ANKOLE, UGANDA.

KARAGWE - ANKOLEAN SYSTEM		Top not seen
	UPPER DIV	q6 to q3 "Sandstone" horizon
	MIDDLE DIV	
	LOWER DIV	q2 Ihunga quartzite
		q1 Boundary quartzite
		q1a Impersistant quartzite
		Calc silicate rocks
	MAJOR UNCONFORMITY.	
TORO SYSTEM	IGARA SERIES ?.	Mica schists (Part of a metamorphic complex including pre K-A granitic rocks)

Chlorite, muscovite, sericite, andalusite, staurolite (see plate 3) garnet (~~see plate~~) and even kyanite (see plate 4) have been formed in the argillaceous rocks situated close to the granites and large scale metasomatic introduction of tourmaline into the arenaceous rocks has occurred in places (see plate 5).

The granitic rocks of S.W. Ankole

The granitic rocks of south-west Ankole are exposed on the floors of shallow topographic basins called arenas and were referred to as arena granites by A.D. Combe in 1932. Several such granites occur and crop out in the Ntungamo, Lugalama, Rufuha, Dwata and Chitwe Arenas (see fig. 1). They consist of updomed masses of injection schist, banded gneiss, streaky and porphyroblastic gneiss, granodiorite, and porphyroblastic biotite granites, which were mobilised to varying degrees during emplacement and show sheared tectonic, sharp intrusive, or gradational migmatitic contacts with the mantling Karagwe Ankolean metasediments.

The arena granites show similarities to the mantled gneiss domes of Eskola (1948), and comparisons between the arena granites and mantled gneiss domes have been made by Harris et al (1951).

The arena granites contain several generations of aplites, secretion pegmatites and early formed pegmatites and quartz veins (see plate 6) as well as numerous later formed quartz-microcline-muscovite pegmatitic granites which transect the earlier granitic rocks and have been intruded into the Karagwe-Ankolean System (see plate 7).

The arena granites were emplaced into the Karagwe-Ankolean System during the Kibaran orogeny, which affected S.W. Uganda 1,290 - 1,181 m.y. ago (V.E. Kennedy 1966), and with the exception of the pegmatitic granites

PLATE 3 (ABOVE).
Staurolite schist showing large staurolite porphyroblasts on weathered surface, Nyakisa Hills.

PLATE 4 (LEFT).
Kyanite schist with kyanite vein, Rwakirenzi Hill.

PLATE 5.

Tourmalinised quartzite with quartz veining,
Burama Ridge.

PLATE 6.

Granite gneiss containing several generations of aplite, early pegmatite and quartz veins, Omunturo.

PLATE 7.

Early pegmatitic granite vein in granite gneiss showing irregular deformed margins, Omunturo Stream.

which are post-tectonic, they consist of:- Pre-Karagwe-Ankolean (possibly Toro) injection schists, gneisses and migmatites; migmatites formed by syntectonic granitisation of Lower Karagwe-Ankolean metasediments; and early-syn- and late-tectonic Kibaran granites (see table 3). The latter have been shown by Kennedy (1966) to have high initial $^{87}Sr:^{86}Sr$ ratios and to include granitic material of pre-Karagwe-Ankolean age, which achieved a quartzo-feldspathic composition during an earlier cycle of tectonism and was remobilised during emplacement into the K-A system. So far rocks of original Toro age have not been identified in the Ankole Anticlinorium and it is still debatable (see footnote) whether the granitic rocks of S.W. Ankole are comprised of elements of completely granitised Toro rocks or granitised pre-Toro basement instead.

The pegmatitic granites are late (post-tectonic) intrusive and hybrid rocks which formed by palingenesis of pre-existing granitic rocks at regional centres of dynamothermal activity, ("hot-spots"). The distribution of the various granitoid rock types is shown on the detailed geological map of S.W. Ankole, (see enclosure 1).

The pegmatitic granites are for the purposes of this thesis the most important granitic rocks in S.W. Ankole, as it is with the

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*Footnote: The writer has found partially granitised injection schists (see enclosure 1), in the vicinity of Lake Karenge, which contain amphibolites, are often biotite rich, and bear little resemblance to the Karagwe Ankolean metasediments found elsewhere. It is possible that these rocks may be Toro in age and that granitised equivalents may make up a substantial proportion of the other granitic rocks emplaced during the Kibaran orogeny.

TABLE 3.

		EVENTS	1 CENTRAL KATANGA M.Y.	2 SOUTH KIVU M.Y.	3 UGANDA & N.RWANDA M.Y.	4 S.W.ANKOLE+	EVENTS IN S.W. ANKOLE
-	POST TECTONIC	"Rejuvenation" of biotite	888 - 795 (locally 699)	540*	520 - 565	568	"Rejuvenation" of micas
7	POST TECTONIC	Second pegmatite episode (younger phase)	875 ± 26*	854 ± 10*	nd**	849	Hydrothermal tin mineralisation
6	POST TECTONIC	Second pegmatite episode (older phase)	912±30* - 955±30	897 ± 27*	950 - 975	987 approx.	Granite pegmatite and post-tectonic pegmatitic granite formation
-	POST TECTONIC	Rejuvenation of muscovite	(890) 906 - 1010	-	-		
5	POST TECTONIC	Equigranular muscovite tin granite	906±30 - 947±54*	926 - 950	nd**	-	
4	POST TECTONIC	First pegmatitic episode and veins	1100*	1120 ± 20	-	nd**	Early aplite and pegmatitic granite veins formed
3	SYNTECTONIC	Late tectonic granite	-	-	1190*	1185, 1190	Chitwe and Ntungamo granites formed
2	SYNTECTONIC	Syntectonic granitisation	1300 ± 40*	nd**	1290*	1290	Rwentobo granite formed
1	SYNTECTONIC	Early tectonic porphyroid granite					

* Rb/Sr isochrons and/or U:Pb determinations

** Phenomena known but age not determined

1 - 3 Data taken from Cahen, L., Delhal, J. & Deutsch, S. (Unpublished paper in preparation, 1966)

4 Additional data supplied by Kennedy, V.E. 1966 (Personal communication)

pegmatitic granites that most of the beryllium mineralisation is associated.

A short account of the nature and distribution of the pegmatitic granites therefore follows.

The post-tectonic pegmatitic granites of S.W. Ankole

The pegmatitic granites are very coarse quartz-microcline-muscovite granites which occur as late-developed pods, patches, schlieren or veins in the granitic rocks, and have been intruded into the Karagwe-Ankolean sediments in the form of dykes, stocks or irregular injections.

A whole range of types occurs from simple quartzo-felspathic secretions to intrusions of pegmatitic granite and complex zoned granite pegmatites.

The simple secretions of pegmatitic granite are the earliest in formation and form concordant microcline-rich schlieren and lenticular bands in granite gneiss, which are often deformed, impersistant, and contain biotite and oligoclase derived from the country rock.

Often permeation and metasomatic 'soaking' of areas of gneiss and migmatites has resulted in the formation of large patches of muscovite rich pegmatitic granite containing giant porphyroblastic crystals of microcline which contain numerous inclusions or have formed graphic intergrowths with quartz. The texture of the pegmatitic granite patches is very variable and ranges from a grain size of ¼ of an inch at the margins up to one or two feet in the centre. Muscovite and sometimes biotite occur as irregular books or interstitial plumose aggregates, and garnet and tourmaline are common accessory minerals (plate 8). The host rocks appear to have been permeated or invaded by replacement without disturbance of pre-existing structures, and contacts with the patches of pegmatitic granite are gradational.

In some cases numerous small veinlets of microcline ramify the host

PLATE 8 (ABOVE).
Patch of coarse pegmatitic granite containing large 2" tourmaline crystals.

PLATE 9 (LEFT).
Late cross-cutting pegmatitic granite vein in granodiorite, 'Stirling-Astaldi' quarry, Ntungamo.

rock particularly along foliation planes, and increase in number and size until continuous patches of pegmatitic granite are produced.

Active migration of material along numerous channelways appears to have played an important part in the formation of the pegmatitic granite and sometimes sufficient magma has accumulated to enable reinjection to occur, with the result that some 'concordant' pegmatitic granite patches pass laterally into cross cutting veins and dykes which may run for considerable distances and have chilled contacts with the country rocks (plate 9).

The most important pegmatitic granites are those which accumulated to form magma which has been reinjected into older granites or Karagwe- Ankolean sediments. Two separate phases of injection of pegmatitic granite veins has been recognised in places. The intrusive pegmatitic granites are usually quartz-muscovite-microcline varieties and contain tourmaline and garnet as accessory minerals. They occur as irregular dykes up to a few feet in thickness and several hundred feet in length which are often coarse grained in texture and have finer grained chilled margins.

Beryl has occasionally been found to occur as an accessory mineral in these pegmatitic granites (A.D. Combe 1932 p.59 and O. von Knorring - personal communication), but occurs in much larger quantities in zoned or replaced pegmatite intrusions which are found in association with (or have differentiated from) pegmatitic granite.

Distribution of the pegmatitic granites

In contrast to the reports of earlier workers (A.D. Combe 1932), and the maps of the Uganda Geological Survey (Bushenyi Sheet 85), the writer has not found a continuous intrusion of pegmatitic granite around Lake Karenge. Instead the Lake Karenge granite has been found to consist of sporadic injections and patchy developments of pegmatitic granite occurring in a complex area of migmatites and injection schists (see fig. 1 enclosure 1). 'Invasion' by pegmatitic granite has taken place without disturbing the regional structure and the foliation directions of the rocks, and in places large undisturbed rafts of migmatite occur almost completely surrounded by pegmatitic granite. Permeation and lit-par-lit injection of the rocks by potash rich material and intrusion of larger sheet-like masses of coarse microcline-rich pegmatitic granite has occurred on a regional scale in the area around Lake Karenge (plate 10).

One large mass of pegmatitic granite (shown ~~red~~ on Map 1 , Enclosure 1) has been intruded into K-A sediments at Rwabaramira Hill to form a stock-like body of pegmatitic granite which has sent out offshoots in the form of pegmatitic granite apophyses and zoned beryl bearing pegmatites. (This intrusion of pegmatitic granite is surrounded by the highest concentration of beryl-bearing pegmatites in S.W. Ankole, see fig. 3, p. 10).

Tin and Beryllium Mineralisation

Widespread tin and beryllium mineralisation has occurred in S.W. Ankole (see fig. 3). The tin mineralisation is represented by the occurrence of quartz-mica and hydrothermal quartz cassiterite-bearing veins which contain the bulk of the tin deposited in S.W. Ankole (in the form of cassiterite) whereas the beryllium mineralisation is represented by the occurrence of numerous beryl bearing granite pegmatites which contain economic concentrations of beryl, columbite and tantalite.

Previous Work

The granite pegmatites

Granite pegmatites containing beryl, columbite-tantalite were discovered in S.W. Ankole before 1932 and were first described by A.D. Combe in Memoir II. of the Geological Survey (1932) p. 59 .

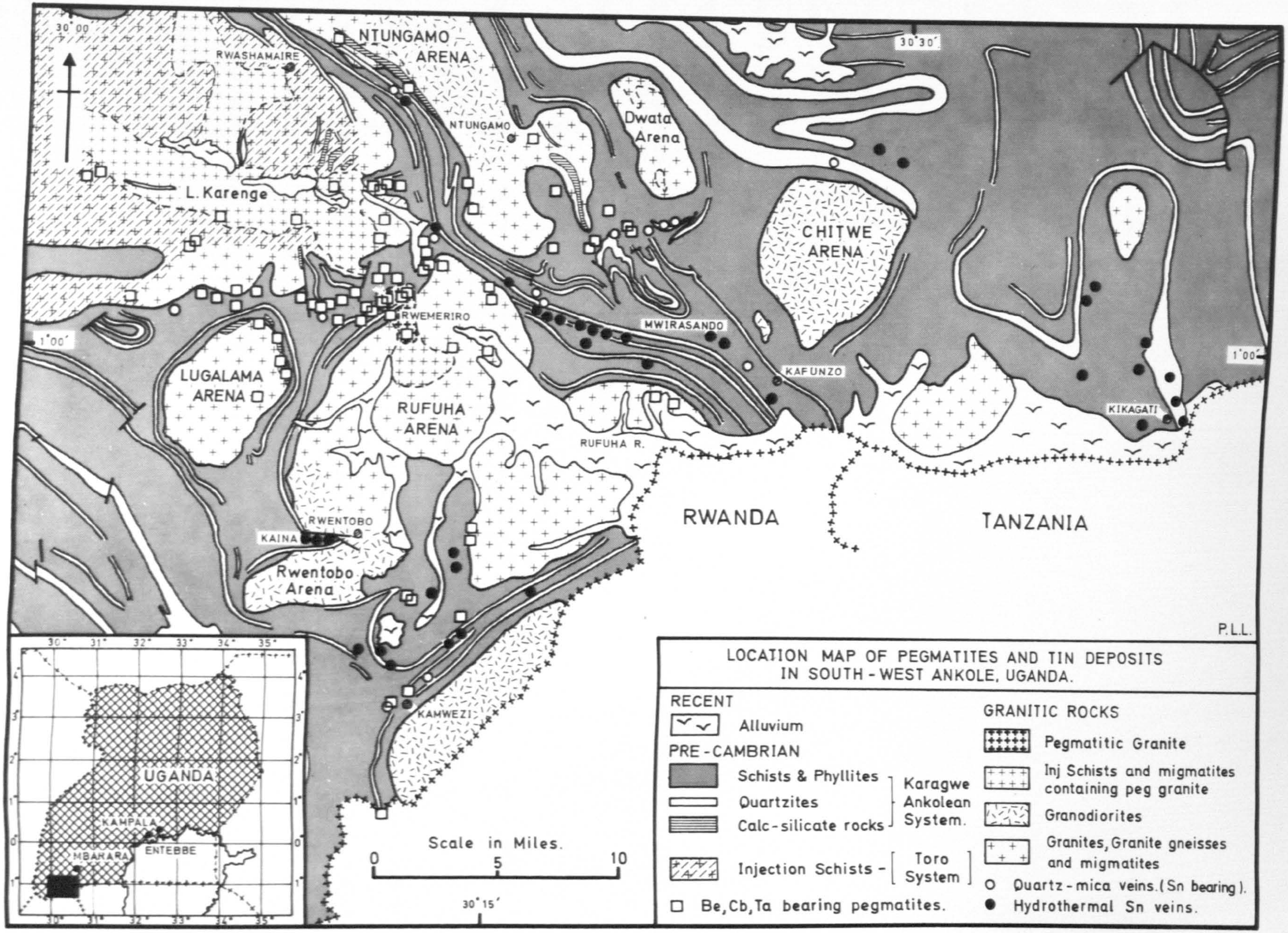
PLATE 10a.

Pegmatitic granite veins in injection schists, Rweibango Hill.

PLATE 10b.

Large intrusive mass of pegmatitic granite in injection schist, East of Einoni Hill.

FIG 3


NTUNGAMO ARENA
RWASHAMAIRE
NTUNGAMO
L. Karenge
Dwata Arena
CHITWE ARENA
LUGALAMA ARENA
RWEMERIRO
MWIRASANDO
KAFUNZO
RUFUHA ARENA
RUFUHA R.
KIKAGATI
RWENTOBO
KAINA
Rwentobo Arena
KAMWEZI
RWANDA
TANZANIA
30°00'
30°30'
1°00'
30°15'
Scale in Miles.
0
5
10
P.L.L.
UGANDA
KAMPALA
ENTEBBE
MBARARA
LOCATION MAP OF PEGMATITES AND TIN DEPOSITS IN SOUTH-WEST ANKOLE, UGANDA.
RECENT
Alluvium
PRE-CAMBRIAN
Schists & Phyllites
Quartzites
Calc-silicate rocks
Karagwe Ankolean System.
Injection Schists - Toro System
Be, Cb, Ta bearing pegmatites.
GRANITIC ROCKS
Pegmatitic Granite
Inj Schists and migmatites containing peg granite
Granodiorites
Granites, Granite gneisses and migmatites
Quartz-mica veins. (Sn bearing).
Hydrothermal Sn veins.

In the following years only a few short reports on columbite-tantalite and beryl bearing pegmatites were published (A.D. Combe) as there was insufficient demand for these minerals to warrant large scale investigation of the deposits. During the 1950's prospecting was stimulated by a marked rise in the price of columbite and several published and unpublished reports describing pegmatite occurrences in S.W. Ankole were prepared by Survey Geologists (J.W. Barnes, P.F. Meal, A.G. Otika, R.C. Pargeter, R.O. Roberts, and F.W. Roe) see bibliography and unpublished reports list - appendix 4. The most important of these was an Unpublished Bulletin No. 4 of the Uganda Geological Survey by J.W. Barnes and P.F. Meal (1959) entitled 'Mineralised Pegmatites in Uganda' in which numerous pegmatites from S.W. Ankole (as well as other areas in Uganda) were described, and a first attempt was made to explain their origin and paragenesis and to relate them to the geology of the area.

In 1959 there was a sharp world demand for beryllium and the United Kingdom Atomic Energy Authority sent a team of geologists to investigate and prospect for beryllium deposits in S.W. Ankole and S. Rhodesia. The results of their work (1959-1961) are incorporated in a series of U.K.A.E.A. and Geological Survey of Great Britain geological and mineralogical reports. Notes on the occurrence of certain minerals from Uganda and S. Rhodesia have been published by J.R. Hawkes and M.J. Gallagher in the Bulletin of the Geological Survey of Great Britain (1966) and in the Mineralogical Magazine (1967).

The most recent Uganda Geological Survey publication dealing with the granite pegmatites is Bulletin No. 4 'The Mineral Resources of Uganda' in which short summaries of the geology of the tin, beryllium, tantalum and niobium deposits of Uganda are given.

The quartz-mica and hydrothermal quartz cassiterite-bearing veins

Cassiterite and cassiterite bearing deposits were first discovered in Karagwe (N.W. Tanzania) in 1924 and then in S.W. Ankole in 1925. The more important deposits were independantly described by A.D. Combe (1932) and H.A. Stheeman (1932) whose publications still stand as the only major works on the subject.

W.C. Simmons (1932) in a post-script to Memoir II of the Geological Survey of Uganda was the first to propose a possible mechanism for the deposition of cassiterite in the deposits of S.W. Ankole.

Since 1932, numerous short reports by Survey Geologists describing the tin deposits of S.W. Ankole have appeared in the literature (see bibliography) and in particular the Annual Reports and Records of the Uganda Geological Survey. The authors include A.D. Combe, K.A. Davis, A.W. Groves, P.F. Meal R.C. Pargeter, W.C. Simmons and E.J. Wayland. There are in addition a large number of unpublished reports by Uganda Survey geologists (see unpublished reports list - appendix 4) which are kept in the Records Office at the Survey Headquarters at Entebbe, and a short summary of the geology of the tin deposits of S.W. Ankole has been published in Bulletin No. 4 (1961) 'The Mineral Resources of Uganda' pp.27-31.

Scope of thesis and problems investigated

The geology of the tin and beryllium mineralisation has been studied and the granitic rocks and associated mineral deposits have been examined with a view to determining their nature, mode of occurrence, time of formation and relationship to each other and to the rocks of the Karagwe Ankolean System.

Particular attention has been paid to the granite pegmatites, as numerous new deposits have been found which have not so far been described. The most important granite pegmatites have been mapped on a large scale and have been classified in their mineralogy and zonal structure. An attempt has also been made to fit the pegmatites of S.W. Ankole into a conventional pegmatite classification scheme.

A geochemical study of the tin and beryllium mineralisation has also been carried out, and numerous samples of all the main rock types have been collected and analysed for tin and beryllium, to study the distribution of these elements and to try to establish a source of the mineralisation. An attempt has also been made to establish the form taken by tin in tin bearing rocks and minerals from Ankole.

A study has also been made of the behaviour of alkalis, fluorine and tin in muscovites from all the mineral deposit types, in order to investigate the possibility suggested by various Russian workers - that tin and beryllium are transported in the form of alkali- or alkali-hydroxy-fluo complexes during the formation of certain types of hydrothermal and pegmatitic tin and beryllium deposits.

Muscovite was chosen as it occurs in close association with tin and beryllium minerals in all the deposits of S.W. Ankole and can incorporate all the 'complex forming' elements in its lattice. (i.e. tin, beryllium, the alkalis and fluorine).

Finally, investigations have been carried out into the possibilities of using the chemical composition of muscovite as an indicator in prospecting for new hydrothermal quartz cassiterite-bearing deposits.

This thesis is divided into three main sections. In the first section (Section 1 chapters I - IV), the geology of the tin and beryllium mineralisation is described and in the following section (Section 2 chapters V - XII), the results of the geochemical investigations are presented together with a summary of new findings. The Appendix (Section 3 appendices I - V) contains:

I. Detailed descriptions of selected type pegmatites of the granite pegmatite groups. (with large scale maps),

II. Geochemical and analytical data including sample location indexes

III. A summary of analytical and experimental techniques used, and a new method for the determination of total tin in rocks and minerals.

IV. An index of unpublished maps and reports on the mineral deposits of S.W. Uganda.

V. A bibliography of all publications referred to in this thesis.

A 1:50,000 geological map of a part of S.W. Ankole, large-scale plans and sections of pegmatites, and tables summarising the geology of every pegmatite and quartz-mica cassiterite bearing vein studied, are presented as enclosures at the back of the thesis.

SECTION I

GEOLOGY OF THE TIN AND BERYLLIUM MINERALISATION

CHAPTER I

THE GRANITE PEGMATITES

THE GRANITE PEGMATITES

Occurrence and Distribution

Numerous beryl-columbite-tantalite bearing granite pegmatites have been found in S.W. Ankole and occur both in Karagwe Ankolean and granitic country rocks. The pegmatites show a close association with major exposures of pegmatitic granite and the largest major exposure of pegmatitic granite occurs at Rwabaramira Hill (~~coloured red on the~~ geological map, enclosure 1). This granite (see also fig. 3) is partially surrounded by an area of K-A country rock which to the north contains the highest concentration of beryl bearing pegmatites in Ankole. This area is believed to be underlain by intrusive pegmatitic granite, and in S.W. Ankole rocks of the K-A system only contain pegmatites when they occur in close proximity to granite.

Pegmatites have also been found within the arena granites and occur particularly where formation of pegmatitic granite has taken place. Marginal and inhomogeneous portions of the arena granites have been found to contain a larger number of pegmatites than homogeneous ones and pegmatites are almost completely absent from the central and homogeneous parts of the Rwentobo, Ntungamo, Chitwe and Ibanda arena 'granites'.

The migmatitic rocks of S.W. Ankole also contain pegmatites and a large number have been found in the area of injection schists and migmatites situated around Lake Karenge. The rocks of this area occupy the core of the Ankole Anticlinorium and have been subjected to the most intense effects of post-tectonic granite formation.

Over 110 pegmatites have been studied by the writer and these have been classified into five main groups (see table 4), and enclosures 2-9.

These groups include pegmatites which contain fresh feldspars and show

FIG 4

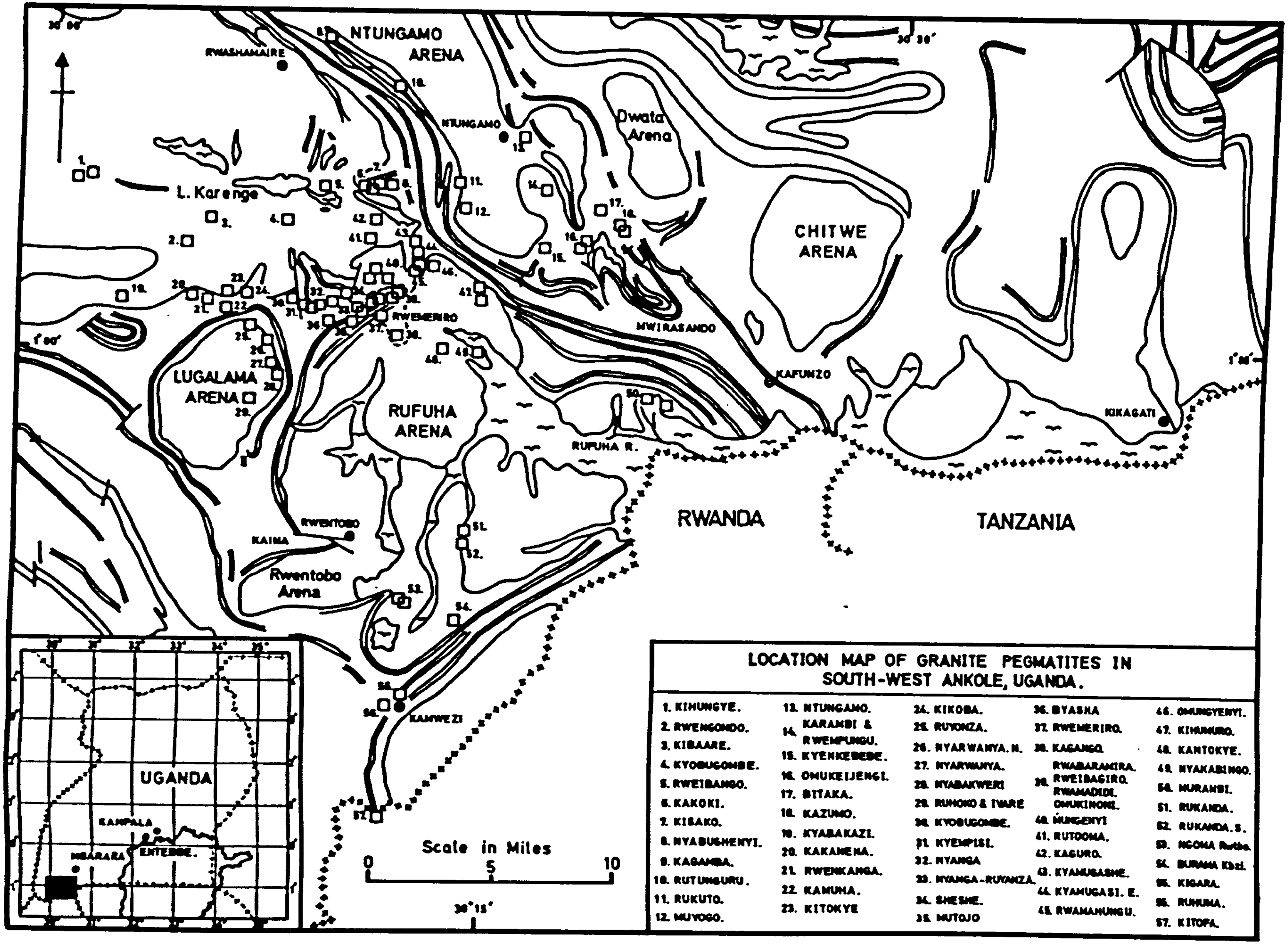

NTUNGAMO ARENA
RWASHAMAIRE
NTUNGAMO
L. Karenge
Dwata Arena
CHITWE ARENA
LUGALAMA ARENA
RUFUHA ARENA
Rwentobo Arena
RWENTOBO
KAINA
RWEMERIRO
MWIRASANDO
KAFUNZO
KIKAGATI
RUFUHA R.
KAMWEZI
RWANDA
TANZANIA
UGANDA
KAMPALA
ENTEBBE
MBARARA
Scale in Miles
0
5
10
30°15'
30°30'
LOCATION MAP OF GRANITE PEGMATITES IN SOUTH-WEST ANKOLE, UGANDA.
1. KIHUNGYE.
2. RWENGONDO.
3. KIBAARE.
4. KYOBUGOMBE.
5. RWEIBANGO.
6. KAKOKI.
7. KISAKO.
8. NYABUSHENYI.
9. KAGAMBA.
10. RUTUNGURU.
11. RUKUTO.
12. MUYOGO.
13. NTUNGAMO.
14. KARAMBI & RWEMPUNGU.
15. KYENKEBEBE.
16. OMUKEIJENGI.
17. BITAKA.
18. KAZUMO.
19. KYABAKAZI.
20. KAKANENA.
21. RWENKANGA.
22. KAMUHA.
23. KITOKYE
24. KIKOBA.
25. RUYONZA.
26. NYARWANYA. N.
27. NYARWANYA.
28. NYABAKWERI
29. RUHOKO & IWARE
30. KYOBUGOMBE.
31. KYEMPISI.
32. NYANGA
33. NYANGA-RUYANZA.
34. SHESHE.
35. MUTOJO
36. BYASHA
37. RWEMERIRO.
38. KAGANGO.
39. RWABARAMIRA. RWEIBAGIRO. RWAMADIDI. OMUKINONI.
40. MUNGENYI
41. RUTOOMA.
42. KAGURO.
43. KYAMUGASHE.
44. KYAMUGASI. E.
45. RWAMAHUNGU.
46. OMUNGYENYI.
47. KIHUMURO.
48. KANTOKYE.
49. NYAKABINGO.
50. MURAMBI.
51. RUKANDA.
52. RUKANDA. S.
53. NGOMA Rutba.
54. BURAMA Kbzi.
55. KIGARA.
56. RUHUMA.
57. KITOFA.

Table 4. CLASSIFICATION OF THE PEGMATITES OF S.W. ANKOLE

GROUP NO.	TITLE	REPLACEMENT TYPE	Poorly Zoned	Fully Zoned	Unaltered	Kaolinised	RELATIONSHIP TO GRANITE
1 a-d	Microcline muscovite pegmatites	None	*	*	*		Interior
			*	*		*	Marginal
2	Albite-muscovite replaced pegmatites	Sodium		*	*		Marginal
3	Kaolinised spodumene-albite replaced pegmatites	Sodium-lithium (Type 1)		*		*	Marginal (sometimes exterior)
4	Lithian muscovite-albite replaced pegmatites	Sodium-lithium (Type 2)		*	*	*	Marginal
5 a,b	Quartz-mica-kaolin pegmatites	?	*	*		*	Exterior

relatively simple zoning (Groups 1a and 1c), and pegmatites which are complex in structure, contain extensive replacement zones, and/or are highly altered and kaolinised (Groups 1b, 1d, 2, 3, 4 and 5). The simple unaltered pegmatites have been found to occur almost entirely within granitic country rock whereas the complex replaced and altered pegmatites have been found to occur in altered marginal portions of the granites and in the adjacent K-A sediments.

The distribution and zonal arrangement of the different pegmatite groups with respect to the granitic rocks is very similar to that described by Gevers (1936) for pegmatites in Namaqualand.

Gevers (Loc cit. pp.339-340) proposed that according to their mode of distribution, pegmatites may be divided into three groups:

a. Interior Pegmatites or Core Pegmatites

b. Marginal Pegmatites or Hood Pegmatites

c. Exterior Pegmatites or Roof Pegmatites

In S.W. Ankole the unaltered microcline muscovite pegmatites (which occur mainly within granitic country rocks) are interior or core pegmatites; the altered pegmatites of groups 1a and 1c and the altered or replaced pegmatites of groups 2 - 4 which occur in marginal granitic or K-A country rock are marginal or hood pegmatites; and the quartz-mica-kaolin pegmatites of group 5 (which occur entirely within K-A country rocks) are exterior roof pegmatites.

The marginal and exterior pegmatites show the strongest replacement, mineralisation and/or alteration, and were formed where conditions were particularly favourable for the accumulation of hydrothermal fluids.

The mineralogy of some of the marginal pegmatites has been found to be affected by the distance from the source granite and this is particularly well illustrated by the pegmatites which surround and are derived from the

Rwabaramira pegmatitic granite intrusion. The pegmatites which occur close to the granite (which is tourmaline bearing) contain more tourmaline than those which occur further away, and the amount of tourmaline in the country rocks has also been found to decrease with increasing distance from the granite.

This is in accord with observations made by Varlamoff, N. (1958), on the reginnal zoning of other pegmatites in Africa.

Description of the pegmatites of S.W. Ankole

Summary of major features

The shape and size of the pegmatite intrusions is very variable and ranges from small concordant lenticular intrusions a few feet in diameter to large irregular cross cutting bodies several hundreds of feet in length. Lenses, dykes, sheets and even phacolithic intrusions have been found in K-A rocks, but in the arena granites the pegmatites tend to form simple dykes.

The contacts of most of the pegmatites with the country rocks are sharp, and frequently show marginal chilling. The country rocks adjacent to the pegmatites are often hydrothermally altered, muscovitised or strongly tourmalinised.

Pegmatites intruded into schists and phyllites frequently take advantage of the country rock schistosity and have been intruded as concordant lenses and sheets. Often however injection has been forceful and the pegmatites transgress or displace the country rock schistosity. In the Karagwe-Ankolean country rocks some movement has usually accompanied pegmatite intrusion with shearing, slickensiding, and small scale drag folding of the wall rocks.

The pegmatites in the granitic rocks tend to fill simple fissures but may branch or anastomose to form a system of ramifying veinlets at their terminations. Sometimes evidence can be found for the derivation of injected

PLATE 11.

Roof contact of pegmatite in K-A schist, Kitoke.

pegmatite material from the granitic country rocks in the vicinity of the pegmatite veins, and then gradual transitions from permeated country rock to pegmatitic granite and finally zoned pegmatite can be observed.

Contacts of the pegmatites in the granitic rocks may be sharp but often where transitions from pegmatite to pegmatitic granite occur the contacts are gradational. Tourmaline often concentrates along the margins of the pegmatites and at the margins of the later replacement zones.

Pegmatites in granite country rock sometimes contain fresh albite feldspar, and in some cases the margins of the intrusions have been partially obscured by albite replacement, which has extended outwards to include the country rock. Unaltered albite has only been found in substantial amounts in pegmatites situated in 'granite' country rock; in pegmatites situated in K-A country rocks the albite is nearly always altered to kaolin.

A conspicuous feature of the pegmatites of S.W. Ankole is the variety of types represented. No two pegmatites have been found which are identical in structure and composition and large variations occur even between pegmatites which have been classified in the same group.

In many cases the mineral paragenesis has proved almost impossible to determine as hydrothermal alteration has obscured the relationships of the minerals and zones. Both simple and complex pegmatites have been found and it is the complex replaced and altered pegmatites that have been found to contain the highest concentrations of economic minerals. These include the deposits which contain (or did contain prior to hydrothermal alteration), albite, lithian muscovite and/or spodumene.

A summary of the mineralogy of the major pegmatite groups of S.W. Ankole is presented in table 5.

TABLE 5

GROUP 1 Microcline-Muscovite Pegmatites

GROUP 2 Albite-Muscovite Replaced Pegmatites

GROUP 3 Spodumene Albite Replaced Pegmatites

GROUP 4 Lithian Muscovite-Albite Replaced Pegmatites

GROUP 5 Quartz-Mica Kaolin Pegmatites

MINERALS	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
MAJOR					
Albite		*	*	*	
Kaolin	*		*	*	*
Lithian Muscovite				*	
Microcline	*	*	*	*	
Muscovite	*	*	*	*	*
Quartz	*	*	*	*	*
Sericite	*		*		*
Spodumene			*	*	

Table 5 . cont'd.

GROUP 1 Microcline-Muscovite Pegmatites

GROUP 2 Albite-Muscovite Replaced Pegmatites

GROUP 3 Spodumene-Albite Replaced Pegmatites

GROUP 4 Lithian Muscovite-Albite Replaced Pegmatites

GROUP 5 Quartz-Mica-Kaolin Pegmatites

MINERALS	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
MINOR					
Albite	*				
Amblygonite			*		
Apatite	*	*	*	*	
+Beryls					
Alkali Free Beryl	*				*
Sodium Beryl		*			
Alkali Beryl			*	*	*
Cassiterite			*	*	*
Columbite	*		*	*	*
Garnets					
Almandine	*	*		*	
Spessartine				*	
Heterosite	*	*	*		
Iron Oxides (limonite)					*
Kaolin		*			

+ Beryl types distinguished by differences in morphology.
Re. Beus, A.A. (1966) p. 79.

Table 5 . cont'd.

GROUP 1 Microcline-Muscovite Pegmatites

GROUP 2 Albite-Muscovite Replaced Pegmatites

GROUP 3 Spodumene-Albite Replaced Pegmatites

GROUP 4 Lithian Muscovite-Albite Replaced Pegmatites

GROUP 5 Quartz-Mica-Kaolin Pegmatites

MINERALS	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
MINOR cont'd.					
Lithian Muscovite			*		
Lithiophilite	*	*	*		
Manganese Oxides	*	*	*	*	*
Metastrengite			*		
Oligoclase	*	*			
Oncosine		*		*	
Sericite		*		*	
Spodumene	?				
Tantalite	*		*	*	*
Tourmalines					
Schorlite	*	*	*	*	*
Verdelite				*	
Zircon			*		

Table 5. cont'd.

GROUP 1 Microcline-Muscovite Pegmatites

GROUP 2 Albite-Muscovite Replaced Pegmatites

GROUP 3 Spodumene-Albite Replaced Pegmatites

GROUP 4 Lithian Muscovite-Albite Replaced Pegmatites

GROUP 5 Quartz-Mica-Kaolin Pegmatites

MINERALS	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
<u>RARE</u>					
Alluaudite			*		
Arrojadite			*		
Bismuth (native)				*	
Cassiterite	*				
Chrysoberyl			*		
Columbite		*			
Coronadite-Hollandite			*		
Goyazite (group)			*		
Graftonite			*		
Grayite	*				
Hureaulite	*				
Leucophosphite	*				
Lipscombite		*	*		
Lithian Muscovite			*		
Lithiophorite			*		
Meta-Ankoleite	*				
Meta-Strengite	*	*			

Table 5 . cont'd.

GROUP 1 Microcline-Muscovite Pegmatites
GROUP 2 Albite-Muscovite Replaced Pegmatites
GROUP 3 Spodumene-Albite Replaced Pegmatites
GROUP 4 Lithian Muscovite-Albite Replaced Pegmatites
GROUP 5 Quartz-Mica-Kaolin Pegmatites

MINERALS	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
RARE cont'd.					
Microlite	*				
Orthoclase				*	
Phospho-Uranylite	*				
Plumbogummite (series)			*		
Pyrite		*		*	
Strengite		*	*		
Tapiolite	*				
Tavorite	*				
Verdelite	*				
Wavellite			*		
Zinc Blende		*		*	
Zircon	*				*
No. of Pegmatites	60	3	10	2	36

Total: 111

CLASSIFICATION AND DETAILED DESCRIPTION OF THE PEGMATITES OF S.W. ANKOLE

Classification

The pegmatites have been classified by the writer into five main groups:-

Group 1. Microcline-muscovite pegmatites

Group 2. Albite-muscovite replaced pegmatites

Group 3. Spodumene-albite replaced pegmatites

Group 4. Lithian muscovite-albite replaced pegmatites

Group 5. Quartz-mica-kaolin pegmatites

The classification scheme adopted is after that proposed by Beus (1956 and 1962) for beryl bearing pegmatites, as it was felt that the majority of the pegmatites of S.W. Ankole can be conveniently placed in this scheme.

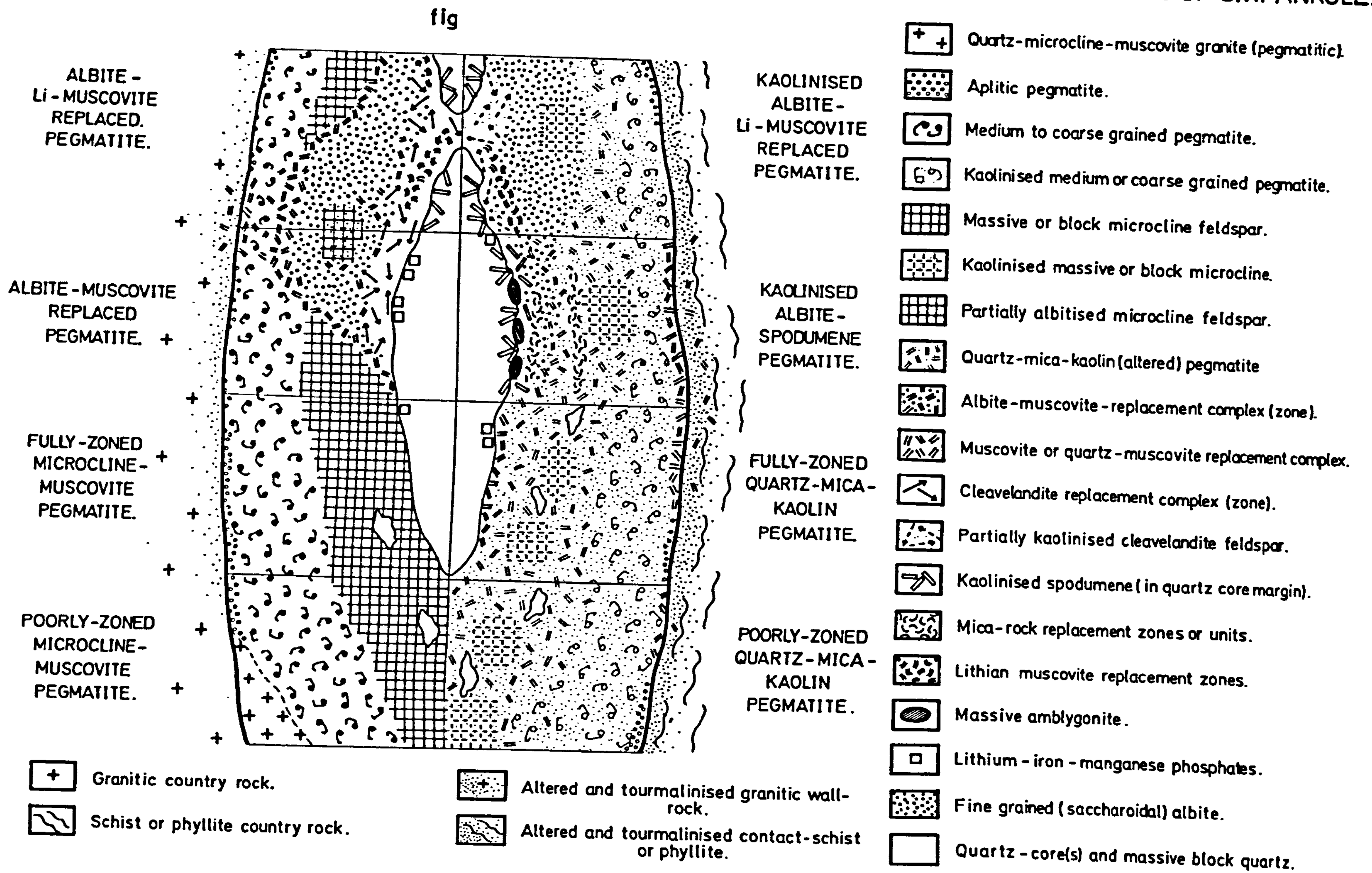
In S.W. Ankole a large number (36) of zoned and unzoned pegmatites have been found which are so extensively altered that no trace of the original feldspars remain. These pegmatites cannot conveniently be placed into the classification scheme proposed by Beus and have therefore been separately classified as 'quartz-mica-kaolin' pegmatites by the writer (Group 5).

A common feature of the pegmatites examined is that both poorly and fully zoned representatives of some of the groups (1 and 5) have been found to occur. The fully zoned pegmatites are those in which a quartz core and clear concentric zoning has developed and the poorly zoned pegmatites are those in which no quartz core has been observed to occur in present exposure (1966) (see fig. 5). It is possible that in a number of cases the absence of a quartz core is due to lack of exposure at the time of the writers visit to the deposit.

A further subdivision of the pegmatites into unaltered and kaolinised types has been made for the pegmatites of group 1, as both fresh and kaolinised

FIG 5

SCHEMATIC DIAGRAM TO SHOW THE STRUCTURE AND COMPOSITION OF THE MAIN PEGMATITE TYPES OF S.W. ANKOLE.



representatives have been found to occur.

It is not certain whether there is any genetic difference between the unaltered and altered (kaolinised) pegmatites but the presence of relatively higher concentrations of muscovite and sericite in the kaolinised pegmatites suggests that these may have been subjected to late-stage hydrothermal alteration. It has also been suggested by Dr. O. von Knorring (personal communication) that the presence of kaolin could be at least in part due to recent (tropical) weathering.

In the pages that follow the characteristic features and mineralogy of the five main pegmatite groups are described, and summary tables are presented at the end of this thesis (see enclosures ~~2a-d, 3, 4, 5, 6a and b~~ 2-9), which outline the geology of every pegmatite studied.

Group 1.

THE MICROCLINE-MUSCOVITE PEGMATITES

Over 60 microcline muscovite pegmatites were studied by the writer (see table 6, enclosures 2-5, and appendix p. 147), and occur both in Karagwe Ankolean sediments and granitic country rocks. The pegmatites which occur in the K-A country rocks or at the margins of the granites are extensively kaolinised, whereas those which occur entirely within granitic rocks are fresh and contain unaltered feldspars.

The microcline muscovite pegmatites are relatively simple in structure and mineralogy, and when fully zoned show the following basic zonal pattern:

1.	Zone of medium to coarse grained pegmatite	Wall Zone
2.	Zone of massive microcline	Intermediate Zone
3.	Zone of block quartz	Quartz

In a few cases a discontinuous aplitic border zone containing minor oligoclase feldspar may occur. The relative proportions of the various zones is very variable and in the poorly zoned pegmatites one or more of the zones may be absent.

Late stage replacement is usually absent or has only occurred on a small scale with the formation of limited quartz-muscovite and albite-muscovite replacement units. Some of the pegmatites have suffered widespread kaolinisation which may or may not be accompanied by the formation of additional muscovite and small quantities of columbite/tantalite.

An outline of the zoning and mineralogy of the pegmatites is given in table 7, which is also arranged to show the paragenesis of the various units.

Table 6 . ALPHABETICAL INDEX OF THE PEGMATITES OF GROUP 1.

Group 1a. The poorly zoned unaltered microcline-muscovite pegmatites

Name	Locality No. Fig. .	Name	Locality No. Fig. .
BITAKA	17	MUYOGO	12
IVARE (Lugalama)	29	NGOMA (U. Location)	53
KARAMBI	14	NYARWANYA	27
KIBAARE (Kigezii)	3	OMUKINONI, N.	39
KYABAKAZI (Ihunga)	19	RUHOKO	29
KYEMPISI. N.E.	31	RUHOKO II.	29
KYENKEKEBE	15	RUKIRA	-
MURAMBI II.	50	RWEMPUNGU W.	14
MUYOGO S.	12		

Group 1b. The kaolinised poorly zoned microline-muscovite pegmatites

Name	Locality No. Fig. .	Name	Locality No. Fig. .
BURAMA - KABEZI	54	MURAMBE I.	50
KIGARA	55	MUTOJO, E.	35
KIKOBA (U. Eastern)	24	MUTOJO. W.	35
KIKOBA (Western)	24	OMUKEIJENGI II.	16
KYAMUGASI, E.	44	OMUKINONI	39
KYEMPISI (Prospects)	31	OMUNGYENYI E.	46
KYEMPISI (N.W.)	31	RWAMAHUNGU (Valley prospect)	46

TABLE 7. THE MICROCLINE-MUSCOVITE PEGMATITES

Stage	Processes	Zones	Major Minerals	Minor and Accessory Minerals	Economic and Ore Minerals
EARLY	PRIMARY CRYSTALLISATION	BORDER ZONE (DISCONTINUOUS, APLITIC)	QUARTZ, MICROCLINE (PLAGIOCLASE SOMETIMES)		
		WALL ZONE (MEDIUM TO COARSE GRAINED PEGMATITE) INTERMEDIATE ZONE MICROCLINE (MASSIVE) CORE MARGIN	QUARTZ, MICROCLINE & MUSCOVITE	BLACK TOURMALINE GARNET AND APATITE	BERYL, COLUMBITE-TANTALITE (TAPIOLITE)
LATE		QUARTZ CORE	QUARTZ	Li/Fe/Mn PHOSPHATES	
LATE STAGE	LIMITED REPLACEMENTS	DISCONTINUOUS INTERNAL REPLACEMENT ZONES	QUARTZ, MUSCOVITE OR ALBITE AND MUSCOVITE	GREEN TOURMALINE ALT. ZIRCON	COLUMBITE-TANTALITE (MICROLITE) CASSITERITE BERYL
		DISCONTINUOUS MARGINAL REPLACEMENT SELVAGES	QUARTZ, MUSCOVITE		
FINAL STAGE	KAOLINISATION (HYDROTHERMAL ALTERATION)	MAY AFFECT ALL ZONES	KAOLIN AND SERICITE (KAOLIN MAY OCCUR AS PSEUDOMORPHS AFTER MICROCLINE OR AS AMORPHOUS PATCHES)	ALTERATION PRODUCTS OF Li/Fe/Mn PHOSPHATES	
	INTRUSION	X CUTTING VEINS	QUARTZ		

MINERALOGY

Major Minerals

Feldspars

Microcline-perthite feldspar or altered microcline feldspar is a major component of the microcline muscovite pegmatites and occurs both as crystals and blocks a few inches to several feet in diameter, and as more continuous masses which extend throughout the intermediate zones (see plates 12 & 13) The feldspar is rarely completely fresh and is often soft, porous in texture, and varies from pale buff to orange-brown or red-brown in colour. Where the feldspar does occur fresh (Ivare, Ruhoko, and Omukinoni.N.) it is white, grey, pale grey, buff or pink in colour, has a vitreous lustre and shows strong perthitic texture. Some of the pegmatites contain large quantities of partly altered microcline (Kyempisi N.E., Murambi, I.) but in others only pseudomorphs of microcline preserved in kaolin occur (Mutojo E. & W. Omungyenyi). Where kaolinisation has been particularly intense all trace of the original microcline disappears and pockets of white kaolin are found instead (Burama-Kabezi, Kikoba, W., Kigara, Kyamugasi East, Mutojo West and Omukinoni).

Muscovite

Muscovite is ubiquitous but tends to concentrate in stringers and aggregates in the wall and intermediate zones. It is more abundant in the altered kaolinised pegmatites than in the unaltered ones and forms marginal replacement zones along the pegmatite and quartz-core margins (plate 14).

The muscovite varies in colour from pale green to amber tinted and silver-grey and books reaching several inches in diameter are fairly common. It usually occurs as intergrowths with quartz and microcline and may form large aggregates in massive microcline feldspar (Mungenyi).

PLATE 12 (LEFT)
Giant microcline feldspar block adjacent to quartz, Kabiga Rukanda.

PLATE 13 (BELOW)
Massive microcline feldspar zone, Kibaare.

PLATE 14.
Muscovite selvage along the footwall margin of the quartz core at Kabiga-Rukanda.

PLATE 15.
Kaolin pseudomorph after block microcline, Kabiga-Rukanda.

Quartz

In the fully zoned pegmatites, quartz forms massive elongate central units or cores and also occurs as irregular wedges and stringers throughout the wall and intermediate zones. The quartz cores often show signs of intense shattering and recrystallisation and must have remained mobile until very late in the paragenesis (Rutooma, Kyobugombe II).

In the unzoned and poorly zoned microcline-muscovite pegmatites the quartz occurs as irregular intergrowths and as wedges and stringers up to one or two feet in diameter; the size of the fragments usually increases towards the centre of the pegmatites where several large aggregates surrounded by massive microcline feldspar, may occur.

Kaolin and sericite

Kaolin is very common in the microcline-muscovite pegmatites and has usually been formed by hydrothermal alteration or weathering of the feldspars. It normally occurs in patches intimately mixed with tiny flakes of sericite, but sometimes forms skeletal pseudomorphs after microcline (Plate 15). In the fully zoned pegmatites the formation of kaolin has been influenced by the presence of the quartz core and kaolinisation is most intense adjacent to the core margins.

Economic, minor and accessory minerals

Beryl

The microcline muscovite pegmatites all contain beryl and quantities ranging from a fraction of a ton to over 54 tons have been obtained from individual deposits.

The unaltered pegmatites contain beryl in the form of subhedral crystals and striated anhedral aggregates which range from a fraction of an inch to several inches in diameter. The beryl is usually found adjacent to stringers and wedges of quartz and occurs throughout the pegmatite matrix. In the pegmatites with quartz cores larger accumulations of beryl are also found adjacent to the quartz core (usually footwall) margins. The beryl then occurs as euhedral hexagonal crystals which range from less than one inch to over three feet in diameter and may reach several feet in length. (Nyabakweri, Rutooma, and Rwengondo).

The beryl crystals at the core margins commonly occur in sporadic pockets each containing several crystals. The crystals are usually embedded in the core quartz and when removed leave hexagonal cavities. In many cases late movement in the quartz core has broken and displaced the crystals giving them a stepped appearance (see plate 16). In one pegmatite (Rutooma) the euhedral beryl crystals radiate outwards in stellate fashion from the quartz core footwall margin into the adjacent microcline zone (plate 17), and the crystals must have grown either by replacing or displacing the microcline feldspar. The problems associated with the occurrence and origin of similar large euhedral crystals in pegmatites have been discussed in detail by R.H. Jahns (1953), who concluded (p. 596) that 'nearly all the giant crystals are formed during what has been designated by most investigators the primary, or magmatic stage of pegmatite development, and hence from liquid under conditions that permitted remarkable growth of a relatively few individuals'. If the conventional patterns of primary crystallisation from the wall zone inwards are accepted in the case of the Rutooma pegmatite, it is difficult to see how the radiating aggregates of euhedral beryl could have grown <u>outwards</u> from the core margin into the surrounding microcline zone without replacing some pre-existing microcline. The only alternative is that the two minerals formed simultaneously and the beryl grew by "shouldering" aside the microcline feldspar.

PLATE 16.

STEPPED BERYL CRYSTAL IN QUARTZ, RUTOOMA.

PLATE 17.

Beryl crystal, Rutooma. Single columnar crystal showing growth outwards from the core margin into the surrounding microcline feldspar zone.

PLATE 18.

Crystals of 'alkali-free' beryl from the Rwengondo pegmatite. The centre crystal is about 1 foot in length.

Giant subhedral and anhedral aggregates of beryl several feet in diameter have been found in some of the fully differentiated deposits and usually occur in massive microcline fairly close to the quartz core. At Mungenyi such a mass of beryl yielded 28 tons of the pure mineral.

The beryl which occurs in the unaltered microcline-muscovite pegmatites is usually an alkali-free variety known locally by the miners of S.W. Ankole as 'crystal beryl' (see plate 18). The crystal beryl varies in colour from blue to blue-green, greenish-yellow and various shades of buff to off white.

The kaolinised pegmatites also contain beryl which often occurs in larger quantities than in the unaltered pegmatites. The beryl usually occurs as friable crystals and anhedral aggregates which may reach several feet in diameter.

In some cases the anhedral masses of friable beryl are very large and examples weighing up to 12,000 lbs. are reported to have been mined (Kabiga-Rukanda). The friable beryl may be found in a matrix of quartz, kaolin or altered microcline feldspar and is difficult to recover as it is usually intimately mixed with fragments of these minerals. The beryl is often ironstained and is coloured buff to red brown.

In a few of the altered pegmatites limited late replacement has led to the formation of small subhedral crystals of beryl in quartz-muscovite replacement zones close to the hanging wall margin of the intrusions (Burama-Kabezi). At Kyamugasi late formed beryl occurs as pale-yellow-green 'stuffed' crystals up to 2" in diameter which contain quartz and muscovite inclusions.

Columbite-Tantalite

Columbite/tantalite has been found in small quantities in many of the microcline-muscovite pegmatites but is most common in the pegmatites with well developed quartz cores, where kaolinisation of the feldspar has occurred. The columbite usually occurs in a matrix of quartz or in altered (kaolinised) microcline adjacent to quartz. The largest accumulations of columbite/tantalite have been found close to the footwall margins of the quartz cores. Production figures for individual pegmatites range from a few pounds to over $\frac{3}{4}$ of a ton (Karabuga) and 1 ton (Nyabakweri).

Tapiolite

Tapiolite is very rare but has been found in very small quantities (25 lbs) in the Ruyonza-Kyobugombe pegmatite, where it occurs as subhedral crystals up to 3" in diameter in the quartz core margin.

Microlite

Fibrous, pale pink aggregates of microlite up to 2" in diameter which contain remnants of unaltered tantalite have been found in the Kyamugasi E. pegmatite. The microlite (which is slightly radioactive) was found associated with stringers of quartz in a matrix of kaolin and muscovite.

Cassiterite

Traces of cassiterite have been found in some of the altered microcline muscovite pegmatites (Kabiga-Rukanda and Kyabakazi-Ihunga) but it is never present in economic amounts. The cassiterite only occurs where patchy replacement has affected the pegmatites and is found either in association with albite and muscovite (Kyabakazi-Ihunga) or in minor quartz-muscovite replacement units adjacent to the quartz core (Kabiga-Rukanda).

Minor and accessory minerals

Albite

Small patchy developments of sugary white granular albite have been observed to occur in the pegmatites that have been affected by localised late-stage albite replacement (Kyabakazi-Ihunga, Mungenyi Main and Rukira).

Apatite

Small subhedral or euhedral crystals of pale-blue apatite have been found where patchy albitisation has affected the pegmatites (Kyabakazi-Ihunga and Rukira). The apatite occurs with muscovite in a matrix of granular albite.

Garnet

Almandine garnet occurs in some of the unaltered fully differentiated pegmatites which are situated in granitic country rock (U. Kihungye, Rweibango and Rwengondo), and forms anhedral aggregates up to a few inches in diameter. The garnet when fresh is pale to dark red in colour, but at U. Kihungye it has been coated with black iron-manganese oxide staining making it difficult to recognise.

Oligoclase

Minor quantities of granular oligoclase feldspar have been found in the chilled border zones of some of the pegmatitles which occur in granitoid country rock.

Li/Fe/Mn Phosphates

Lithium-iron-manganese and iron-manganese phosphates have been found in some of the altered and unaltered fully zoned microcline-muscovite pegmatites (Kabiga-Rukanda, Kibaare, Kihumuro and Mungenyi Main). The phosphates generally occur as brown or black altered nodules up to two feet in diameter which must be broken open to reveal the fresh phosphate minerals. The nodules are usually found adjacent to quartz in a matrix of altered or partially altered microcline feldspar and are late in formation.

At Kabiga-Rukanda boulders of lithiophilite with thick black alteration rims occur adjacent to the quartz core. The lithiophilite when fresh is coarsely crystalline, pale green to grey-brown in colour and has a sub-vitreous to greasy lustre. Partial alteration within the lithiophilite has produced thin films of bright yellow-green tavorite along the cleavage planes (plate 19).

At Kibaare lithiophilite is also the most common phosphate but contains small quantities of pyrite. Small quantities of a reddish brown phosphate hureaulite occurs together with the lithiophilite and nodules of maroon coloured heterosite coated with pale blue metastrengite have been separately found.

At Kihumuro lithiophilite also occurs but has been substantially altered and the nodules are surrounded by thick black rims which contain heterosite, pale blue meta-strengite, and mauve coloured leucophosphite. (~~plate~~). Tavorite derived by alteration of the lithiophilite also occurs along the cleavages of the lithiophilite. The lithiophilite has also been observed to pass marginally into translucent dark reddish hureaulite (similar to that found at Kibaare) and sometimes contains stringers of silver grey mica. Heterosite only has been found at Mungenyi. The writer is indebted to Dr. O. von Knorring for identification of the phosphate minerals.

Manganese Oxides and Iron-Manganese oxides

Mn oxides and Fe/Mn oxides have been found in these pegmatites which contain Li/Fe/Mn or Fe/Mn phosphates. The oxides are derived by weathering or hydrothermal alteration of the phosphates and form thick coatings around them. The oxides frequently stain the pegmatite matrix in the vicinity

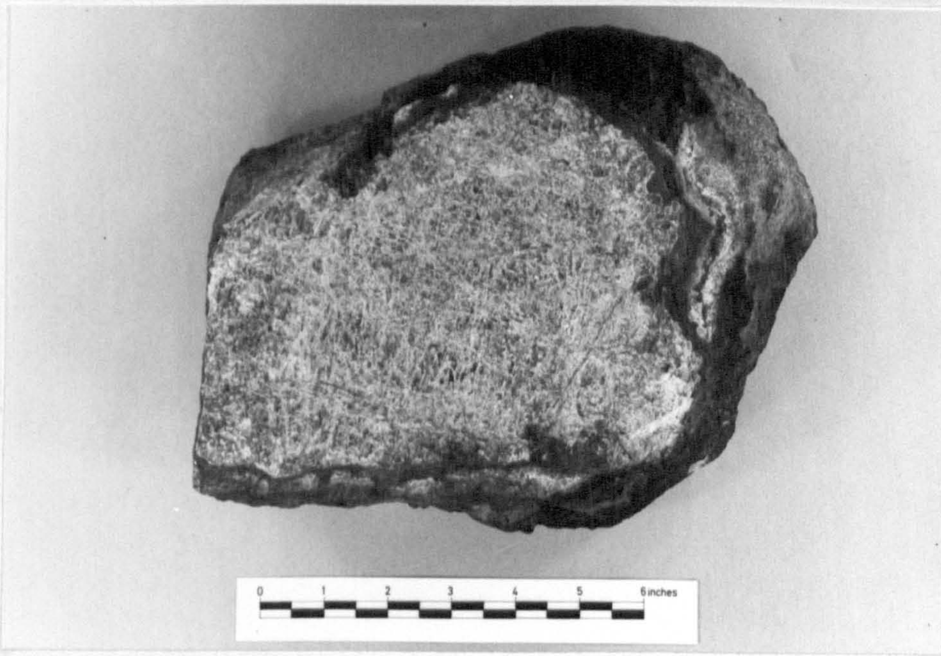


PLATE 19.

Nodule of lithiophilite with rim of dark coloured alteration products, Kabiga-Rukanda.

of the phosphate nodules.

Manganese and iron-manganese oxide staining has also been found in some pegmatites which do not contain phosphates (Kigara).

Tourmaline

Black tourmaline (schorlite) is a common accessory mineral and occurs both concentrated at the margins of the pegmatites (Bitaka, Upper Kihungye, Kibaare) and as subhedral crystals throughout the wall and intermediate zones. Euhedral tourmaline crystals have also been found along the quartz core foot-wall margins at Rutooma and Rweibango.

Green tourmaline

A single porphyroblastic crystal of green tourmaline 3 inches in length, which contains numerous small inclusions of muscovite orientated parallel to the c-axis has been found in spoil taken from the Mungenyi (main) pegmatite. The crystal is believed to have formed by replacement.

Miscellaneous minerals

Grayite, Meta-Ankoleite and Phospho-uranylite

Meta-Ankoleite - a hydrated potassium uranyl phosphate has been reported to have been obtained from the Mungenyi pegmatite by M.J. Gallacher (1966), and occurs in the form of yellow scaly aggregates of thin flakes up to 1 mm. in diameter together with phosphouranylite minerals and grayite. The meta-ankoleite fluoresces yellow-green under ultra-violet light. The above minerals are very rare and are of mineralogical interest only.

Zircon

Altered zircon in the form of small pale brown crystals up to ½" in diameter has been found to occur in association with columbite/tantalite in many of the pegmatites.

Group 2.

THE ALBITE-MUSCOVITE REPLACED PEGMATITES

Only three examples of this pegmatite type have so far been found in S.W. Ankole (see table 8, enclosure 5, and appendix pp.149), and all are characterised by the presence of widespread albite and muscovite replacement complexes, which occur superimposed on the basic zonal pattern of the microcline-muscovite pegmatites of group 1. The following major zones have been recognised in the albite muscovite replaced pegmatites.

a.	Zone of aplite-like pegmatite	Border Zone
b.	Zone of medium to coarse grained pegmatite	Wall zone
c.	Zone of massive microcline	Intermediate zone
d.	Zone of block quartz	Quartz core
e.	Muscovite replacement complex	Replacement zones
f.	Cleavelandite-albite replacement complex	

Kaolinisation occurs only on a limited scale and in one case (Nyakabingo) the feldspars were found to be fresh throughout the pegmatite. An outline of the zoning, mineralogy and paragenesis of the pegmatites is given in table 9. The albite muscovite replaced pegmatites have been found to occur either in granitic country rocks or in partially granitised injection schists.

MINERALOGY

Major Minerals

Albite

In the albite-muscovite replaced pegmatites albite or cleavelandite-albite is the predominant feldspar. In all the pegmatites examined, albite can be seen to preogressively replace microcline until replacement zones containing saccharoidal albite or pure white bladed cleavelandite are produced.

Table 8 . ALPHABETICAL INDEX OF THE PEGMATITES OF GROUP 2.

The albite-muscovite replaced pegmatites

Name	Locality No. Fig. .
Representative example.	
NYAKABINGO	49
Remainder of group	
KITOKYE	23
NGOMA (S. Location)	53

TABLE 9. ALBITE-MUSCOVITE REPLACED PEGMATITES

PROCESSES		ZONES	MAJOR MINERALS	MINOR AND ACCESSORY MINERALS	ECONOMIC AND ORE MINERALS
EARLY	PRIMARY CRYSTALL-ISATION	BORDER ZONE (APLITIC)	QUARTZ, MICROCLINE (PLAGIOCLASE SOMETIMES)		
		WALL ZONE (ZONE OF MEDIUM TO COARSE GRAINED PEGMATITE)	QUARTZ, MICROCLINE & MUSCOVITE	BLACK TOURMALINE & GARNET	
		INTERMEDIATE ZONE (ZONE OF BLOCK MICROCLINE)			
LATE		QUARTZ CORE	QUARTZ	Li/Fe/Mn PHOSPHATES	(BERYL)
LATER	REPLACEMENTS	MUSCOVITE REPLACEMENT COMPLEX CONTAINING QUARTZ/MUSCOVITE ZONES	QUARTZ, MUSCOVITE	APATITE & GARNET	BERYL ALKALI (SODIUM) BERYL (MINOR COLUMBITE)
		ALBITE REPLACEMENT COMPLEX CONTAINING CLEAVELANDITE ZONES	QUARTZ, ALBITE MUSCOVITE		
		PATCHY MICA ROCK REPLACEMENT	QUARTZ, ONCOSINE, MUSCOVITE		
FINAL STAGE	KAOLINISATION (HYDROTHERMAL ALTERATION)	OCCASIONAL PATCHES	KAOLIN	ALTERATION PRODUCTS OF Li/Fe/Mn PHOSPHATES	(ZINC BLENDE)

The albite is usually fresh and at Kitokye albitisation occurs beyond the margins of the pegmatite in portions of the adjacent (granitic) wall rocks.

Quartz, Microcline and Muscovite

The distribution of quartz muscovite, and microcline in the albite-muscovite replaced pegmatites is similar to that in the microcline-muscovite pegmatites with the exception that the microcline is largely replaced by albite, and additional muscovite has been introduced in the form of stringers, aggregates and replacement selvages in the albite replacement zones (complex). The muscovite selvages are most commonly developed along the margins of the albite replacement zones and along the hanging and footwall margins of the replaced pegmatites. The selvages consist mainly of coarse books and plumose aggregates of pale green muscovite up to several inches in diameter which are often arranged perpendicular to the pegmatite contacts.

Kaolin

Kaolinisation is not usually widespread in the albite-muscovite replaced pegmatites but patches of kaolin and sericite do occur where alteration has affected microcline or albite feldspar.

Economic, Minor and Accessory Minerals

Beryl

Alkali (var. sodium) beryl is the main variety of beryl to be found in the albite-muscovite replaced pegmatites and is usually apple green to pale greenish-white in colour. The most typical varieties of alkali beryl have been found at Nyakabingo where it occurs throughout the cleavelandite replacement zones as pale-green crystals from ½" to 6" in diameter which have truncated, pyramidal, conical and skeletal habits (plate 21). The crystals often contain cores of albite and quartz showing apographic structure and are known as 'stuffed' beryl crystals (Beus, 1966, p.77-83). The stuffed

PLATE 20 (LEFT)
Alkali beryl in matrix of cleavelandite feldspar and muscovite, Nyakabingo pegmatite.

PLATE 21 (BELOW)
'Stuffed' crystals of alkali (sodium) beryl from Nyakabingo.

crystals commonly have continuous margins of green beryl up to 1" in thickness, which sometimes consist of several flattened beryl crystals lying adjacent to each other which assume a hexagonal form and partially or completely enclose a core of apographic quartz and cleavelandite containing further plates of green beryl. Some of the larger crystals are built up of a large number of regularly orientated tabular crystals in parallel intergrowth with albite and sometimes cone-in-cone structure occurs, in which one, two, or three crystals of beryl nest inside each other, and are separated by sheaths of albite. The crystals all have very uneven outer faces and are separated from each other by irregular and poorly defined margins.

Small inclusions of muscovite are common in the crystals particularly at their outer margins. Not all the beryl crystals in the albite-muscovite replaced pegmatites are of the 'stuffed' variety and some subhedral prismatic crystals of pure beryl also occur (Kitokye and Nyakabingo).

At Nyakabingo over 100 tons of alkali beryl were mined from the cleavelandite replacement zone mainly on the footwall side of the quartz core.

Columbite-tantalite

Columbite-tantalite is conspicuously rare in the albite-muscovite pegmatites and only very small quantities have been observed to occur where the pegmatites are kaolinised.

Apatite

Apatite occurs as an accessory mineral in the pegmatites and at Nyakabingo occurs in association with almandine garnet in the cleavelandite replacement complex.

Garnet

Anhedral masses of almandine garnet up to 1 foot in diameter have been found in the hanging wall cleavelandite replacement zone of the Nyakabingo pegmatite. Scattered smaller crystals also occur on the footwall side of the same pegmatite.

"Oncosine" mica and Sericite

Small quantities of pale green, massive, cryptocrystalline "oncosine" mica-rock occur in late stage replacement units in one of the pegmatites (Nyakabingo) "Oncosine" or very fine grained green muscovite and sericite are abundant throughout the cleavelandite replacement complex at Nyakabingo and impart a green colour to the feldspar.

Oligoclase

Saccharoidal oligoclase feldspar occurs as a minor constituent of the chilled border zone of the Kitakye pegmatite.

Tourmaline

Tourmaline has been found as an accessory mineral in the albite-muscovite replaced pegmatites but is much less common than in the microcline-muscovite types. The tourmaline occurs in the form of tiny prismatic crystals and at Kitokye a discontinuous narrow selvage of these crystals has been found within the border zone, (plate 22a,b).

Lithium-Iron-Manganese Phosphates

Large nodules of altered and weathered lithium-iron-manganese phosphates up to three feet in diameter have been found in one of the pegmatites (Kitokye). The phosphates occur along the quartz core margin in the cleavelandite replacement zones in a matrix of broken core quartz, and cleavelandite feldspar.

Some of the nodules have been found to contain inclusions of pale grey muscovite, veinlets of cleavelandite, and small quantities of sphalerite and pyrite.

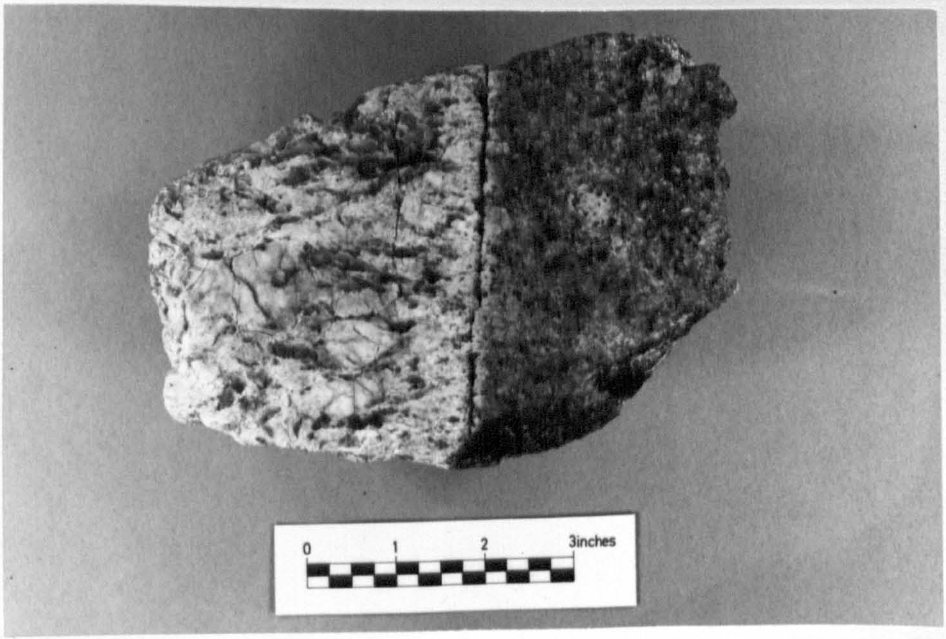


PLATE 22a.
Handspecimen from contact of the Kitokye pegmatite showing selvage of tiny black tourmaline crystals in border zone.

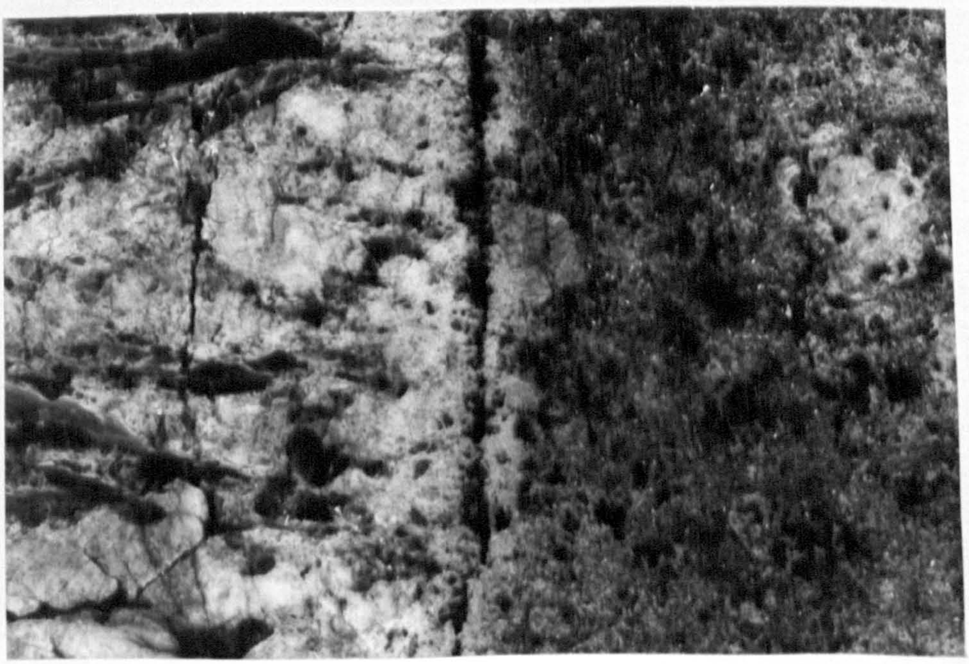


PLATE 22b.
Detail of contact (Mag x $1\frac{1}{2}$)

Several varieties of phosphate have been identified (Dr. O. von Knorring):-

a. Lithiophilite $Li(Mn,Fe)PO_4$

b. Heterosite $(Fe,Mn)PO_4$

c. Strengite and meta-strengite $FePO_4 \cdot 2H_2O$

d. Lipscombite

The most important is the primary phosphate lithiophilite, which frequently forms the cores of the phosphate nodules. Portions of the lithiophilite are stained deep green by alteration along fractures and cleavage to a dark green cryptocrystalline secondary phosphate which may belong to the lipscombite group. The lithiophilite cores of the phosphate nodules are usually surrounded by rims of secondary Fe/Mn phosphates. In one case the lithiophilite is surrounded by a selvage of flesh pink cryptocrystalline strengite, which is in turn surrounded by a massive outer layer of maroon coloured heterosite (Plate 24). Usually however the lithiophilite is directly surrounded by heterosite and sometimes pure heterosite forms the whole of the nodules. One nodule of altered heterosite was found which contained coatings of pale blue meta-strengite.

Manganese and Iron-Manganese Oxides

Manganese and iron-manganese oxides form an outer brown or black weathered layer to most of the phosphate nodules and also stain the pegmatite matrix in the vicinity of the Li/Fe/Mn phosphates.

Pyrite

Small quantities of weathered pyrite have been found in broken core quartz adjacent to some of the phosphate nodules at Kitokye. Pyrite also forms small inclusions up to ¼" in diameter in lithiophilite in the

PLATE 23.

Nodules of iron-manganese phosphate in the Kitokye pegmatite.

PLATE 24.

Lithiophilite surrounded by selvage of flesh pink cryptocrystalline strengite (light) and maroon coloured heterosite (dark), Kitokye.

interior of some of the nodules.

Zinc Blende

Sphalerite occurs as small aggregates up to ¼" in diameter in lithiophilite (from Kitokye) and is a very deep brown 'specular' iron-rich variety.

Group 3

THE SPODUMENE-ALBITE REPLACED PEGMATITES

In S.W. Ankole at least 9 kaolinised pegmatites have been found (see table 10, enclosure 6 and appendix pp.155), which are characterised by the presence of some unaltered or partially altered albite and kaolinised spodumene laths. The internal structure of the pegmatites is on the whole difficult to determine as kaolinisation of the feldspars has tended to obscure the zoning.

In many cases relics of microcline feldspar have made it possible to recognise remnants of the original wall and intermediate zones and all the pegmatites have well developed quartz cores. The margins of the quartz cores are in most cases irregular and contain kaolinised spodumene laths. The pegmatites have all suffered extensive late stage replacement and hydrothermal alteration which has resulted in the formation of muscovite replacement complexes containing zones of coarse quartz, muscovite, albite and kaolin. The replacement zones occur throughout the pegmatites but are particularly well developed where concentration and accumulation of volatiles has occurred, i.e. along the footwall margins of the quartz cores and adjacent to the roof and hanging wall contacts of the intrusions.

In addition to the quartz-muscovite replacement zones, some of the pegmatites also contain a 'greisen' replacement complex consisting of one or more zones of medium-grained muscovite rock that cross cut the earlier zones of crystallisation and replacement, and are late in formation.

The following major zones have been recognised in the spodumene-albite replaced pegmatites.

Table 10 . ALPHABETICAL INDEX OF THE PEGMATITES OF GROUP 3.
The kaolinised spodumene-albite replaced pegmatites

Name	Locality No. Fig.
Representative example.	
NYABUSHENYI	8
Remainder of group.	
BYASHA	36
KAZUMO N.	18
KAZUMO S.	18
NYANGA - RWENTARE	32
RUHUMA C.	56
RWANZA	-
Lr. RWENKANGA	21
U. RWENKANGA	21

Altered

a.	Zone of medium to coarse grained pegmatite	Wall Zone
b.	Altered zone of massive microcline	Intermediate Z.
c.	Zone of block quartz	Quartz core
d.	Muscovite replacement complex consisting of: quartz-muscovite replacement zones and albite-muscovite replacement zones	Replacement zones
e.	'Greisen' replacement complex	Replacement zones

An outline of the zoning, mineralogy and paragenesis of the pegmatites is given in table 11.

The kaolinised spodumene-albite replaced pegmatites have all been found to occur either in K-A schist country rock or in hydrothermally altered granite close to its contact with K-A schists.

MINERALOGY

Major Minerals

The feldspars

In S.W. Ankole the spodumene-albite replaced pegmatites have all been extensively kaolinised and only small quantities of albite or original microcline remain. Where microcline can be found it shows a similar distribution to that occurring in the microcline-muscovite pegmatites. The distribution of albite is such as to suggest that widespread albitisation of the original zones containing microcline occurred before kaolinisation took place.

Quartz

Quartz is very abundant in the spodumene-albite replaced pegmatites, forms massive and irregular quartz cores, and occurs as wedges, stringers

TABLE 11. THE SPODUMENE-ALBITE REPLACED PEGMATITES

	PROCESSES	ZONES	MAJOR MINERALS	MINOR AND ACCESSORY MINERALS	ECONOMIC AND ORE MINERALS
EARLY LATE	PRIMARY CRYSTALL-ISATION	REMNANTS OF WALL ZONE REMNANTS OF INTERMEDIATE ZONE CORE MARGIN QUARTZ CORE	QUARTZ, MICROCLINE (NOW ALTERED), MUSCOVITE SPODUMENE LATHS, (NOW ALTERED)	BLACK TOURMALINE Li/Fe/Mn PHOSPHATES	BERYL COLUMBITE-TANTALITE AMBLYGONITE
LATE	REPLACEMENTS (WIDESPREAD)	MUSCOVITE REPLACEMENT COMPLEX CONTAINING QUARTZ-MUSCOVITE REPLACEMENT ZONES AND ALBITE MUSCOVITE ZONES ALBITE REPLACEMENT COMPLEX CONTAINING ALBITE REPLACEMENT ZONES MICA ROCK REPLACEMENT COMPLEX (CONSISTING OF ROCK AND "GREISEN" UNITS)	QUARTZ, MUSCOVITE (ALBITE) ALBITE QUARTZ, MUSCOVITE	BLUE-GREEN TOURMALINE ALTERED ZIRCON	COLUMBITE-TANTALITE BERYL CHRYSOBERYL COLUMBITE-TANTALITE CASSITERITE
FINAL STAGE	KAOLINISATION (HYDROTHERMAL ALTERATION)	WIDESPREAD AFFECTS MOST OF PEGMATITE	KAOLIN SERICITE CLAYS	ALTERATION PRODUCTS OF Li/Fe/Mn PHOSPHATES (Mn MINERALS)	

and irregular masses throughout the wall, intermediate zones and replacement complexes.

Muscovite

Muscovite is ubiquitous and forms selvages to the pegmatites, coarse intergrowths with quartz, albite feldspar and/or kaolin, and also occurs as medium grained mica rock ('greisen' replacement) units. The colour of the muscovite when fresh is pale-green to yellow-green but when slightly weathered is ironstained pale yellow-brown.

Kaolin and Sericite

Kaolin occurs throughout the pegmatites in the form of homogeneous patches, as a matrix interstitial to quartz and muscovite, and as pseudomorphs after microcline. Fine grained sericite is also abundant and occurs together with the kaolin.

Spodumene (altered)

Large laths or lath-shaped impressions of highly altered spodumene occur at the margins of the quartz cores of all the pegmatites in this group (Plates 25 and 27). The laths which may reach several feet in length now consist of a fine grained mixture of white to pale-pink clay minerals (possibly belonging to the montmorillonite group) and kaolin, and little or no evidence as to their original composition remains. Chemical analyses (O. von Knorring - personal communication 1968) have shown that lithium is now almost completely absent from the laths but comparison with similar material collected from pegmatites in Rwanda (plate 26) (which also contain partially altered spodumene) suggests that the material could once have been spodumene. Results suggest that in S.W. Ankole the spodumene in the kaolinised spodumene-albite replaced pegmatites has been completely altered to clay minerals with an attendant loss of lithium from the spodumene.

PLATE 25 (LEFT)
Altered spodumene laths in kaolinised massive microcline, Byasha.

PLATE 26 (BELOW)
Altered giant spodumene laths in the Rongi pegmatite, Rwanda.

Economic, minor and accessory minerals

Beryl

Beryl is an important constituent of many of the kaolinised spodumene-albite replaced pegmatites and quantities ranging from 70 tons (Kazumo and Rwenkanga) to over 400 tons (Rwanza-Kabira) have been obtained.

The distribution of beryl is very irregular and it can occur anywhere in the replacement complexes. In some of the deposits beryl has been found to increase in abundance as the quartz core is approached and large quantities can occur at the core margins (Nyabushenyi and Rwanza-Kabira).

Larger quantities of beryl are usually found on the footwall side of the quartz core than on the hanging wall side but on occasion substantial concentrations have also been found close to the hanging wall contacts of the pegmatites (Nyabushenyi).

The beryl most commonly occurs as anhedral broken aggregates or as intergrowths with quartz and muscovite in the replacement zones. In some cases the beryl has been intensely shattered and reduced to small grains (Byasha) but more usually occurs as broken fragments from $\frac{1}{4}$ to 1 or 2 inches in diameter. At Rwanza-Kabira massive blocks of very coarsely crystalline beryl weighing several tons each have been mined from adjacent to the quartz core. Some of the pegmatites (Kazumo and Rwenkanga) also contain subhedral "stuffed" crystals of beryl up to 4" in diameter which contain kernels of quartz and these are usually found where strong albite replacement has occurred.

The colour of the beryl is very variable and several differently coloured varieties may occur in any one deposit. The anhedral and broken aggregates are usually yellow-brown and ironstained, but on cleaning may be seen to be colourless, white, greenish or bluish-white, or various shades of cream. Beryl in strongly albitised portions of the pegmatites is usually white or pale greenish-white and is probably an alkali variety.

Chrysoberyl

Small quantities of chrysoberyl have been found in the replacement zone at the margin of the Rwenkanga pegmatite, and occurs in the form of small disseminated granules 0.1 - 0.4 mm. across. (Gallagher and Hawkes 1966 and Geol. Surv. of G.B. Atomic Energy Div. unpubl. rep. 962, 1959).

The chrysoberyl occurs in very much smaller quantities than beryl and has probably formed as a result of enrichment of alumina (and desilication) in the pegmatite during late stages of crystallisation (Re: Beus 1962 p. 31-32). The country rocks of the pegmatite are aluminous, garnet - bearing schists and phyllites and may have contributed (by contamination) to the alumina content of the pegmatite.

Columbite-tantalite

Substantial quantities of columbite/tantalite have been obtained from some of the pegmatites and at Kyamugashe and Ruhuma the columbite-tantalite content exceeded that of beryl.

The columbite-tantalite usually occurs close to the quartz core and forms bladed crystals up to a few inches in length in massive quartz or in quartz-mica-kaolin replacement pegmatite. At Ruhuma C. small crystals of tantalite occur together with kaolinised spodumene laths and stringers of muscovite at the core margin. In some cases as at Nyabushenyi and Kyamugashe, columbite also occurs in late mica rock or 'greisen' replacement units.

Production figures for columbite-tantalite from the pegmatites range from a fraction of a ton (0.03 tons at Rwenkanga) to over two tons at Kyamugashe and Nyabushenyi. The Rwanza-Kabira pegmatite (which has produced over 400 tons of beryl) has produced well over 3 tons of columbite-tantalite.

Cassiterite

Minor quantities of cassiterite have been found in many of the pegmatites and usually occurs closely associated with mica rock or 'greisen' replacement zones, or in portions of the pegmatites which contain albite or are kaolinised. The 'pegmatitic' cassiterite is usually dark black and either occurs as small subhedral crystals in quartz or aggregates of muscovite or can occur as much larger anhedral masses up to 6" in diameter in a matrix of muscovite, broken quartz, and kaolin (as at Rwanza-Kabira).

The cassiterite is late in formation as it has been found as overgrowths on columbite (Rwanza) and in late formed replacement units (Kyamugashe and Nyabushenyi). Over 0.5 tons of cassiterite have been obtained from the Rwanza pegmatite.

Amblygonite

Large boulders of amblygonite up to several feet in diameter have been found at Kazumo, Kyamugashe, Nyanga Main, Nyabushenyi and Rwanza-Kabira, and all occur close to the quartz cores of the pegmatites.

The boulders usually have an outer brownish weathered crust which has been shown by O. von Knorring (1962), to consist of hydrated aluminium phosphate. (Further work by M.J. Gallagher and J.R. Hawkes 1966, indicates that at Nyanga Main the amblygonite (montebrasite) boulders have been superficially altered to kaolin and a barium-calcium-aluminium phosphate of the goyazite group).

The amblygonite when fresh is pure white to pale pink in colour but at

Nyanga Main boulders showing a brecciated texture have been found which contain ramifying veinlets of pale grey cryptocrystalline apatite and small crystals of a reddish brown phosphate of the plumbogummite series (O. von Knorring, 1962).

At Kazumo and Nyabushenyi small crystals and veinlets of pale blue apatite have also been observed in amblygonite.

Amblygonite is believed by the writer to have formed late in the pegmatites as it has been found to contain inclusions of columbite at Rwanza and Nyabushenyi (see photo, plate 27). It is likely that the amblygonite was formed later than the beryl, columbite and spodumene.

Wavellite

Wavellite $Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$ has been found in amblygonite at Kazumo S. It occurs as thin films, has a characteristic radiating fibrous structure and fluoresces bright green under S.W. ultra-violet light.

Lithium-iron-manganese phosphates

Hydrothermal phosphates have been found in very large quantities at Rwanza-Kabira and massive blocks up to several feet in diameter have been found in the replacement zones adjacent to the quartz core.

The following phosphates from Rwanza have been described by Dr. O. von Knorring (von Knorring and Hornung 1965, von Knorring 1967).

1. Alluaudite $(Na,Fe^{+++},Mn^{++})PO_4$
2. Arrojadite $(Na,K,Ca)_2(Fe^{++},Mn^{++})_5(PO_4)_4$
3. Graftonite $(Fe,Mn,Ca)_3(PO_4)_2$
4. Heterosite $(Fe^{+++},Mn^{+++})PO_4$
5. Hureaulite $(Mn,Fe)_5H_2(PO_4)_4 \cdot 4H_2O$
6. Lithiophilite $Li(Mn^{++},Fe^{++})PO_4$

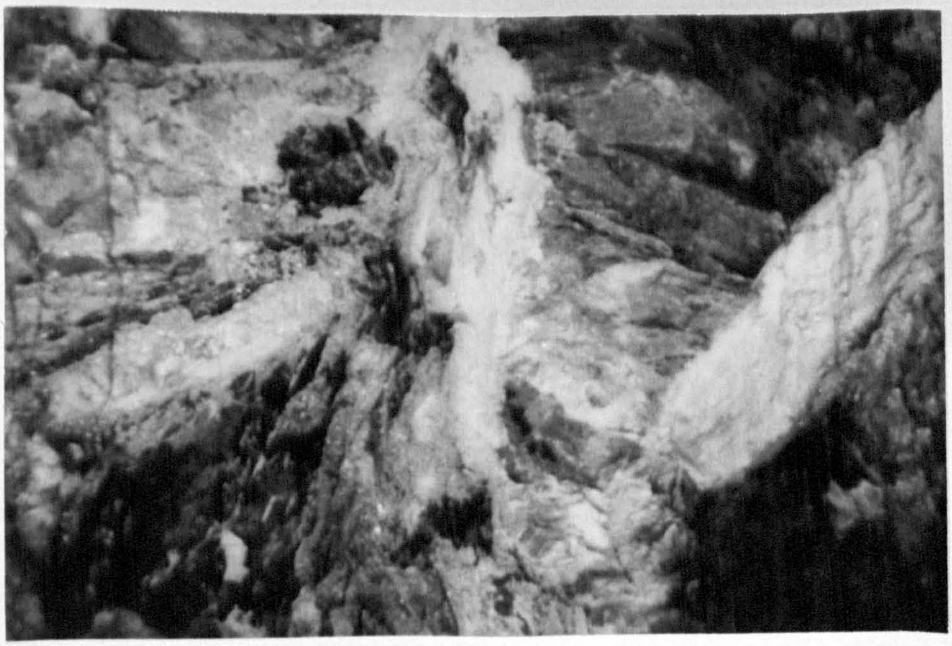


PLATE 27.

Columbite and altered spodumene laths in quartz core, Nyabushenyi.

PLATE 28.

Columbite in amblygonite. Handspecimen from Rwanza-Kabira.

7. Phosphosiderite $FePO_4 \cdot 2H_2O$

8. Strengite $FePO_4 \cdot 2H_2O$.(pink) and Meta-strengite (blue)

9. Manganoan lipscombite

Specimens of these minerals have also been collected by the writer and have kindly been identified by Dr. von Knorring using X-ray powder photographs.

Heterosite is the most abundant phosphate at Rwanza and large boulders of mauve coloured heterosite with coatings of bright blue metastrengite have been exposed in opencast workings on the pegmatite quartz core (plate 29).
Careful examination of some of the boulders reveals that the heterosite has formed by alteration of lithiophilite and is a secondary phosphate.

Some of the phosphate masses at Rwanza have been found to be weakly radioactive and contain tiny specks of a uranium ? mineral which fluoresces bright yellow green under ultra-violet light.

Other Manganese Minerals

In addition to Iron-manganese phosphates, other manganese minerals have been found in some of the pegmatites. At Kazumo black manganese minerals are common, and occur as dark blebs and ring structures in the wall zone pegmatite, and form scaly coatings on quartz. The mineral has been identified by the Geol. Survey of G.B. Atomic Energy Div., as lithiophorite (Re: unpublished Min. Rep. 941, 1959).

At Byasha black earthy patches of manganese oxides have been found associated with coarse replacement pegmatite and these have been identified as belonging to the coronadite-hollandite series (G.S.G.B. A.E.D. Min. Rept. 1067, 1961).

Tourmaline

Black tourmaline (schorlite) has been found as an accessory mineral

PLATE 29.
Nodule of heterosite (maroon coloured) in the quartz core at Rwanza-Kabira.

PLATE 30.
Giant tourmaline crystals in the quartz core margin, Rwanza-Kabira.

in some of the spodumene-albite replaced pegmatites and usually occurs as small prismatic crystals in the wall zones. At Kazumo S. and Byasha, blue-green or altered soft pale-blue tourmaline has been found in altered portions of the pegmatites.

At Rwanza-Kabira, very large quantities of black tourmaline occur at the margin of the quartz core in the form of radiating groups of giant columnar crystals in which individual crystals often reach several feet in length (see photo, plate 30).

Group 4.

THE LITHIAN-MUSCOVITE* ALBITE REPLACED PEGMATITES

Only two lithian-muscovite* albite replaced pegmatites have so far been found in S.W. Ankole at Mutaka and Rwemeriro (see enclosures 7 - and appendix pp.160), and both are characterised by the presence of albite (cleavelandite) and lithian muscovite replacement complexes. The Mutaka pegmatite differs from the Rwemeriro pegmatite in that it has been kaolinised with widespread obliteration of its zonal structure.

The following zones have been recognised in the lithian muscovite replaced pegmatites:-

a.	Contact Zone (Rwemeriro only)	Border Zone
b.	Zone of graphic pegmatite (Rwemeriro only)	Wall zones
c.	Zone of medium to coarse grained pegmatite	Wall zones
d.	Zone of massive microcline	Intermediate Zone
e.	Zone of block quartz	Quartz core
f.	Muscovite replacement complex	Replacement zones
g.	Albite replacement complex	Replacement zones
h.	Lithian muscovite replacement complex	Replacement zones

The lithian-muscovite-albite replaced pegmatites resemble the albite-muscovite replaced pegmatites (Group 2) in that they contain abundant albite or cleavelandite albite feldspar but differ in that they have been subjected

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*Footnote: The presence of lithian muscovite instead of true lepidolite in the Rwemeriro and Mutaka pegmatites (see p.48), has made it necessary to classify them as lithian-muscovite albite replaced pegmatites rather than lepidolite albite replaced pegmatites. re: Beus 1962).

Table 12. ALPHABETICAL INDEX OF THE PEGMATITES OF GROUP 4.
The lithian muscovite-albite replaced pegmatites

	Locality No. Fig. .
Representative example.	
RWEMERIRO	37
Remainder of group.	
MUTAKA	-

to a phase of lithium concentration and contain spodumene (now altered) and lithian muscovite replacement units.

The presence of lithian muscovite distinguishes the lithian muscovite-albite replaced pegmatites from the spodumene-albite pegmatites (Group 3) in which concentration of lithium has resulted in the formation of amblygonite and Li/Fe/Mn phosphates instead. An outline of the zoning mineralogy and paragenesis of the lithian-muscovite-albite replaced pegmatites is presented in table 13, p. 46.

MINERALOGY

Major Minerals

Albite

Albite or cleavelandite albite feldspar is the main feldspar in the Lithian-muscovite-albite replaced pegmatites, and occurs in replacement zones which together constitute the albite replacement complex. The albite shows similar textures and distribution to that found in the albite-muscovite replaced pegmatites of group 2, (see pp.29-30).

One difference is that at Rwemeriro several phases of albite replacement have been recognised. In the earlier ones microcline was simply replaced by albite without very much destruction of the original pegmatitic textures but in the later phases of albitisation, recrystallisation of earlier granular albite to form cleavelandite, and fresh introductions of cleavelandite also occurred, which obliterated all earlier textures and resulted in tthe formation of almost pure cleavelandite replacement zones. These zones occur mainly adjacent to the quartz core (footwall) and were formed where albitisation was most intense.

TABLE 13. THE LITHIAN MUSCOVITE ALBITE REPLACED PEGMATITES....

	PROCESSES	ZONES	MAJOR MINERALS	MINOR AND ACCESSORY MINERALS	ECONOMIC AND ORE MINERALS
EARLY → LATE	PRIMARY CRYSTALLISATION	CONTACT ZONE WALL ZONE (Z. OF GRAPHIC PEGMATITE Z. OF MEDIUM GRAINED PEGMATITE) INTERMEDIATE ZONE (Z. OF BLOCK MICROCLINE)	QUARTZ, MICROCLINE MUSCOVITE	BLACK TOURMALINE	(BERYL) COLUMBITE-TANTALITE
		QUARTZ CORE	SPODUMENE LATHS (NOW ALTERED)		
EARLY → LATE	LATE REPLACEMENT	MUSCOVITE REPLACEMENT COMPLEX CONTAINING QUARTZ-MUSCOVITE REPLACEMENT ZONES, ALBITE-MUSCOVITE REPLACEMENT ZONES	QUARTZ MUSCOVITE		
		ALBITE REPLACEMENT COMPLEX CONTAINING ALBITE AND CLEAVELANDITE REPLACEMENT ZONES	MUSCOVITE ONCOSINE ALBITE CLEAVELANDITE	BLACK TOURMALINE GREEN TOURMALINE GARNET APATITE	COLUMBITE/TANTALITE BERYL (COLOURED) {GREEN → BLUE → WHITE → PINK → ORANGE}
		LITHIAN MUSCOVITE REPLACEMENT COMPLEX CONTAINING ALBITE-LITHIAN MUSCOVITE ZONES AND LITHIAN MUSCOVITE ROCK UNITS	LITHIAN MUSCOVITE CLEAVELANDITE		BERYL CASSITERITE
FINAL STAGE	KAOLINISATION (HYDROTHERMAL ALTERATION)	WIDESPREAD OR RESTRICTED TO CORE MARGIN	KAOLIN AND CLAY MINERALS	MANGANESE OXIDES	(ZINC BLENDE) PYRITE

Microcline

Microcline feldspar does occur in the lithian-muscovite-albite pegmatites but is only found where the early (primary) zones of crystallisation have escaped later albitisation. When unaltered, the microcline shows the same textural relationships and distribution as that found in the microcline-muscovite pegmatites of group 1.

Where partial albitisation has occurred (as at the margins of the albite replacement complex), the microcline can be observed to have undergone a progressive and gradual transformation into albite with preservation of the original textures.

Where kaolinisation has also affected the pegmatites any microcline remaining is preferentially altered to kaolin and at Mutaka large masses of microcline have been kaolinised.

Large blocks of perfectly fresh microcline have been found in the quartz core margin at Rwemeriro where they have been protected from later alteration.

Quartz

Quarz is ubiquitous in the lithian-muscovite-albite replaced pegmatites and all have massive well developed quartz cores. The quartz is usually massive, fractured and milky white in colour, but granular and/or smoky varieties which appear to have been formed by recrystallisation also occur. In some cases the quartz cores appear also to have suffered cataclasis.

The distribution of quartz elsewhere in the pegmatites is similar to that in the other types of zoned pegmatite, but recrystallisation and redistribution of quartz has occurred where late replacement has been most intense.

Muscovite

Muscovite occurs throughout the pegmatites both as an early mineral in the zones of primary crystallisation and as late replacements in the albite replacement complex.

Several varieties of muscovite have been recognised including "ruby" mica which at Rwemeriro occurs as large books up to 1 foot in diameter in a muscovite replacement selvage on the hanging wall side of the pegmatite. Replacement muscovite often marks the limits of the cleavelandite replacement zones where it occurs as discontinuous selvages intergrown with quartz and cleavelandite (see plate 31).

Lithian muscovite

Medium to fine grained massive lithian-muscovite rock, aggregates of small flakes of lithian-muscovite, or globular overgrowths of lithian-muscovite on muscovite have been found to occur in the lithian-muscovite albite replaced pegmatites. The lithian muscovites are very late in formation and have been observed to form distinct replacement units within the albite replacement complex at Mutaka (see plate 32) and Rwemeriro.

The distribution of the lithian muscovite is frequently sporadic and radiating clusters have been found to occur around small crystals of columbite, apatite, garnet and green tourmaline and form nodules in the late cleavelandite replacement zones. Many of the clusters of lithian muscovite appear to have formed around nucleation centres and grown outwards replacing cleavelandite feldspar. On occasion pre-existing muscovite has formed the growth centres for overgrowths of lithian muscovite (Rwemeriro).

The lithian muscovites are silver grey, pinkish lilac or mauve in colour and have an appearance very similar to true lepidolite.

Chemical analyses (see tables 42 , ~~pp.~~ 44), show that the lithium bearing micas from Mutaka and Rwemeriro contain relatively low concentrations of Li_2O, i.e.: from 0.95% in M12 from Mutaka to 2.2% in MO_{R3} from Rwemeriro.

PLATE 31
Muscovite replacement selvage at margin of cleavelandite replacement zone, Rwemeriro.
(Photo G. Hornung)

PLATE 32
Lithian muscovite replacement unit in kaolinised albite, Mutaka.

PLATE 33.
Kaolinised albite with lithian muscovite (silvergrey), clay (brown) and tourmaline (black). Footwall side of quartz core, Mutaka.

The muscovite-lepidolite series has been investigated in detail by Levinson (1953) with subsequent modifications by Smith and Yoder (1956). Levinson concluded that the series muscovite-lepidolite is divisable into a number of stages, on the basis of X-ray studies, which can be correlated with chemical composition, in particular the variation of Li_2O, i.e.:

	Muscovite	-	Lithian Muscovite	-	Lepidolites
Li_2O	0 - 3.3%		3.3 - 4.0%		$>$ 4.0%

On this basis of this system all micas containing less than 3.3% Li_2O are classified as muscovites and the lithium bearing micas from Mutaka and Rwemeriro must therefore also be classified as muscovites.

X-ray diffraction studies carried out by the writer (see table 14) show that the lithium bearing micas from Mutaka and Rwemeriro are the 3T trigonal polymorph of muscovite and differ in structure from both true $2M_1$ lithian muscovite and the lepidolites as defined in the A.S.T.M. powder diffraction file (1967) and by Levinson (1953).

The lithium bearing micas from these pegmatites should strictly be classified as 3T trigonal lithium bearing muscovites but in this thesis they will be referred to as lithian muscovites as this is the only convenient concise term that can be used to describe them.

It is suggested that until specific names are proposed for the individual lithium bearing polymorphs of muscovite, the term lithian muscovite should be employed in a chemical sense to describe any polymorph of muscovite containing $>$ 0.5% Li_2O.

Thelithian muscovites from Rwemeriro are interesting in that they have been found to contain up to 5% fluorine and 1.7% manganese (MnO), see table 42 .

The presence of 5% fluorine in muscovite is very unusual and the

TABLE 14. X-RAY POWDER DIFFRACTION DATA FOR COMPARISON OF THE LITHIUM BEARING MICAS FROM MUTAKA AND RWEMERIRO WITH MUSCOVITES, LITHIAN MUSCOVITES AND LEPIDOLITES.

Radiation: Copper K_1 = 1.54050 (4 strongest lines)

I MO_{R3}		II MO_{R1}		III M11		IV M30		V M35		VI 3T Musc.		
dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1	hkl
9.99	88	9.97	92	9.97	99	9.94	92	9.97	96	9.97	100	003
4.98	33	4.98	49	4.99	38	4.98	50	4.99	43	4.99	55	006
3.32	100	3.33	100	3.33	100	3.33	100	3.33	100	3.33	100	009
1.99	30	1.99	41	1.99	42	1.99	43	1.99	40	1.99	45	00, 15

VII $2M_1$ Musc.		VIII $2M_1$ Lithian M.		IX 1M Lep.		X $2M_2$ Lep.		XI 3T Lep.	
dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1	dÅ	I/I_1
9.95	95	10.0	60	10.0	75	10.0	60	10.0	50
3.32	100	3.32	80	4.99	75	2.58	100	4.98	50
2.57	55	2.85	100	3.62	75	1.99	80	3.32	100
1.99	45	2.58	80	3.34	100	-	-	2.58	75

Table 14. Cont'd.

I.	MO_{R3}	Lithium bearing muscovite (silver-grey, globular var.), Rwemeriro pegmatite.
II.	MO_{R1}	Lithium bearing muscovite (mauve, massive, mica rock), Rwemeriro pegmatite.
III.	M11	Lithium bearing muscovite (silver-grey, mica rock), Mutaka pegmatite.
IV.	M30	Muscovite (greenish-yellow, mica rock), Kazumo pegmatite.
V.	M35	Muscovite (greenish-yellow, mica rock), Rwenyena quartz-mica, cassiterite-bearing vein.

VI.	3T muscovite	For details of locations and references see A.S.T.M. Powder Diffraction File (1967).
VII.	$2M_1$ muscovite	
VIII.	$2M_1$ lithian muscovite	
IX.	1M lepidolite	
X.	$2M_2$ lepidolite	
XI.	3T lepidolite	

manganese is believed to be responsible for the grey to lilac or mauve colour of the lithian muscovites.

Spodumene (altered)

Large radiating groups of lath-shaped spodumene crystals and hollow impressions of spodumene crystals have been found along portions of the quartz core margins. The spodumene laths which are now altered to clay minerals (see p.37) or have been completely dissolved away, are believed to have formed prior to consolidation of the quartz cores and penetrate them to a considerable depth. Their formation is believed to have preceded the main phases of albite replacement (during which they were probably altered).

Kaolin and Sericite

Widespread kaolinisation has affected one of the two pegmatites (Mutaka) and large patches of kaolin with sericite replace microcline and albite. Kaolin also occurs in the form of pseudomorphs after microcline and spodumene.

Economic, minor and accessory minerals

Beryl

Several generations of beryl have been recognised in the lithian muscovite albite pegmatites and all are relatively late in formation. The earliest generation occurs in association with muscovite at the margins of the (cleavelandite) albite replacement complexes, particularly where these lie in contact with unaltered massive microcline or coarse quartz-microcline muscovite pegmatite (i.e. the original wall and intermediate zones of the pegmatites).

The early beryl is pale green in colour but is often iron-stained buff to greenish-brown. At Rwemeriro crystals of pale green beryl with bluish margins have also been found within the albite replacement complex and these contain marginal inclusions of garnet, apatite, columbite and cleavelandite and show that the beryl is later than these minerals in formation.

Blue beryl or bluish-green beryl also occurs throughout the albite replacement complex and in the cleavelandite replacement zones at Rwemeriro and is the most abundant type in the pegmatite. It occurs both as subhedral prismatic crystals from ½" to a few inches in diameter and as larger anhedral crystals which often exceed 1 foot in diameter. The larger masses occur particularly in the cleavelandite replacement zones nearest the quartz core and are often glassy or transparent.

In addition to pure blue beryl a zoned subhedral beryl crystal has been found at Rwemeriro which was pale blue at the base, white in the central portion and pale to strong pink in its upper portion. The colours merged gradationally and the pink zone which partially enclosed the blue and whitish zones was the last to form. Small quantities of white and pale pink beryl have also been found separately in the cleavelandite replacement zones close to the quartz core. Similarly coloured beryls have also been found at the Mutaka pegmatite but here white or stained-white alkali beryl is the most common type.

Orange beryl has also been found at Rwemeriro along portions of the quartz core footwall where late stage lithian muscovite replacement has also occurred. The orange beryl is an alkali-rich variety and forms tabular crystals 1 or 2" in thickness and up to 6" in length. The crystals are frequently found adjacent to kaolinised spodumene laths in the quartz core margins and occur in a matrix of cleavelandite feldspar and quartz.

Although no overgrowths of orange beryl on pink have been found, there can be no doubt that the orange beryl was the last type to form. Crystals showing a gradual transition from pink to orange have been found.

From observations made at Rwemeriro the series:-

Green beryl	—	Blue-green beryl	—	Blue beryl	—	White beryl	—	Pink beryl	—	Orange beryl
(early alkali 'poor' variety)			⟶			(late alkali 'rich' variety)				

can be constructed. The series shows that as replacement progressed a series of beryls containing increasing concentrations of alkalis was produced from early to late. This series reflects a progressive increase in the concentration of alkalis present in the residual fluids in the pegmatites as replacement occurred. This is supported by the observation that lithian muscovite (i.e. lithium bearing mica) is one of the last minerals to form in the replacement zones of the pegmatites.

Very large quantities of beryl have been recovered from the albite-lithian muscovite replaced pegmatites and up to December 1966, 200 tons had been recovered from Mutaka and over 450 tons from Rwemeriro.

Columbite-tantalite

Columbite-tantalite occurs in the lithian-muscovite replaced pegmatites either at the core margins or in the adjacent cleavelandite replacement zones.

Large quantities (over 2 tons) of columbite have been found in situ in the replacement zones at Mutaka where kaolinisation has occurred, and the columbite occurs in pockets, as aggregates of bladed crystals, together with broken quartz and muscovite. One such pocket yielded an excellent euhedral crystal which is shown in the photograph ~~opposite~~ (plate 34).

At Rwemeriro only small quanities of columbite have been found in situ either as bladed crystals adjacent to the quartz core, or as skeletal crystals up to 1 inch in length which contain cores of granular albite,

PLATE 34.

Euhedral crystal of columbite from Mutaka.

in the cleavelandite replacement zones. Small quantities have also been found in association with late stage lithian muscovite replacement units and occur as small prismatic crystals together with laths of greenish-blue apatite and radiating aggregates of lilac grey lithian muscovite. Approximately 5 tons of detrital columbite-tantalite have been found at Rwemeriro on the downhill side of the pegmatite and the ore is believed to have been derived (by erosion) from the roof of the main quartz core.

Cassiterite

Cassiterite has been found both at Rwemeriro and Mutaka pegmatites and in both deposits has been deposited at a late stage in the albite replacement complexes. The cassiterite from the pegmatites is always dark black in colour and occurs as small subhedral crystals or anhedral aggregates up to 4" in diameter.

At Mutaka over 1 ton of cassiterite has been obtained from the albite-lithian-muscovite replacement complex where the ore occurs intergrown with lithian muscovite rock units, or in a matrix of quartz, altered albite, kaolin and lithian muscovite. Specimens have been found of aggregates of lithian muscovite containing small crystals of cassiterite which have in turn been overgrown with white alkali-beryl. The specimens show that the cassiterite was formed just prior to the lithian muscovite and the latest generation of beryl.

At Rwemeriro only small quantities of cassiterite have been found and it occurs as subhedral to anhedral crystals up to 4" in diameter which replace, and are intergrown with cleavelandite feldspar. Some of the cassiterite encloses small prismatic crystals of columbite indicating that the cassiterite is later in formation.

Apatite

Apatite occurs in the lithian muscovite-albite replaced pegmatites and several differently coloured varieties ofmanganoan-apatite have been found in the cleavelandite replacement zones at Rwemeriro (see p. 171).

The apatites have kindly been analysed by M.H. Kerr and J.R. Baldwin to see whether there is any relationship between the intensity of colouration and the manganese content (see table 15). It was expected that dark-blue manganoan apatite ARL 1 would contain the highest concentration of manganese but the results show that it contains the least amount (2.36% MnO). The dark blue-green apatite ARL 2 has been found to contain the most manganese (5.94% MnO), and the lightest coloured apatite ARL 4 (which was expected to contain the least manganese) contains 1.53% more MnO than the darkest one (ARL 1).

Garnet

Garnet is fairly common in portions of the albite replacement complexes of both lithian-muscovite albite replaced pegmatites.

At Rwemeriro the garnet is sometimes dark red in colour and vitreous (var Almandine) and contains occasional inclusions of columbite. A pale peach coloured altered variety of garnet has also been found adjacent to the footwall margins of the quartz core and occurs as irregular masses up to 2" in diameter together with cleavelandite, small euhedral crystals of orthoclase feldspar, and manganese oxides. Chemical analysis (see table 42) shows that the garnet is a spessartine variety with an unusually high manganese content (37% MnO).

At Mutaka small amounts of peach coloured garnet have also been found associated with lithian muscovite where late stage replacement has occurred. This garnet occurs as small euhedral crystals from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in

TABLE 15. CHEMICAL ANALYSES OF MANGANOAN APATITES FROM RWEMERIRO

	ARL 1 (Dark blue)	ARL 4 (Pale yellow-green)	ARL 3 (Pale blue-green)	ARL 2 (Dark blue-green)
MnO	2.36	3.89	5.16 ~~5.94~~	5.94
CaO	53.15	51.80	50.23	49.10
P_2O_5	42.05	41.61	42.28	41.66
F	1.48	1.63	1.65	2.91
H_2O^+ / H_2O^-	0.43	-	-	0.50
	99.47	98.93	99.32	100.41
Less O = F	0.62	-	-	1.22
	98.85	98.93	99.32	98.89 ~~99.19~~
Insolubles	-	0.52	-	0.30
Total	98.85	99.45	99.32	99.49

ARL 1 & 2 Analyst: M.H. Kerr

ARL 3 & 4 Analyst: J.R. Baldwin

diameter and one crystal has been found to contain inclusions of black cassiterite and is clearly later than cassiterite in formation.

"Oncosine"

At Rwemeriro there has been extensive development of a massive replacement rock which consists of medium grained platy white albite which is intimately intergrown with pale green cryptocrystalline "oncosine" mica. The rock which is coloured pale green by the "oncosine" is devoid of any economic minerals.

Tourmaline

Two varieties of tourmaline have been recognised in the lithian-muscovite-albite replaced pegmatites:- a) Black tourmaline - schorlite
b) Green tourmaline - verdelite

a) Schorlite

Schorlite tourmaline is a ubiquitous accessory mineral in the pegmatites and occurs both in the early zones of primary crystallisation and in the later replacement zones.

At Rwemeriro, large striated crystals of schorlite up to several inches in length occur in the contact and wall zones in a matrix of quartz, microcline feldspar and muscovite. Graphic intergrowths of quartz and tourmaline have also been found. Black tourmaline has also been found in the albite replacement complex and often a line of large prismatic tourmaline crystals marks the boundary or outer margin of individual replacement zones (see section 4, enclosure 20 , and photo, plate 35).

At Mutaka large early-formed crystals of schorlite have been found in the intermediate zone adjacent to the quartz core footwall margin. The tourmaline has been strongly fractured as a result of late movement in

PLATE 35.
Prismatic crystals of black tourmaline at the margins of replacement zones, Rwemeriro. (Photo G. Hornung).

the pegmatite and the crystals have a stepped appearance. The fractures have been infilled by films of muscovite and sericite.

b) Green tourmaline - verdelite

Green tourmaline has been found in minor amounts in both pegmatites and is always associated with late stage lithian-muscovite replacement units. At Rwemeriro small quantities of olive-green tourmaline occurs as small striated prismatic crystals or as overgrowths on earlier black tourmaline. The green tourmaline is sometimes in turn overgrown by radiating aggregates of lithian muscovite which partly replace or form intergrowths with the tourmaline (see plate 36).

At Mutaka dark green tourmaline occurs intergrown with lithian muscovite but some gently curved and fractured, striated prismatic crystals of apple-green tourmaline have been found in granular core-quartz in portions of the pegmatite where late stage replacement has occurred (plate 37)..

Analyses of schorlite and verdelite from Rwemeriro are presented in table 42 . They show that the schorlite is iron-rich (11.02% total iron) and contains unusually high magnesium (4.3% MgO), and that the verdelite is rich in manganese (1.66% MnO) and contains relatively high lithium (1.25% Li_2O) and fluorine (1.46% F).

Miscellaneous minerals

Native Bismuth

A small piece of metallic bismuth weighing less than an ounce is reported to have been found at Rwemeriro.

Manganese oxides

Manganese oxides are common in parts of the cleavelandite replacement zones as black staining which forms thin films along the cleavages of the

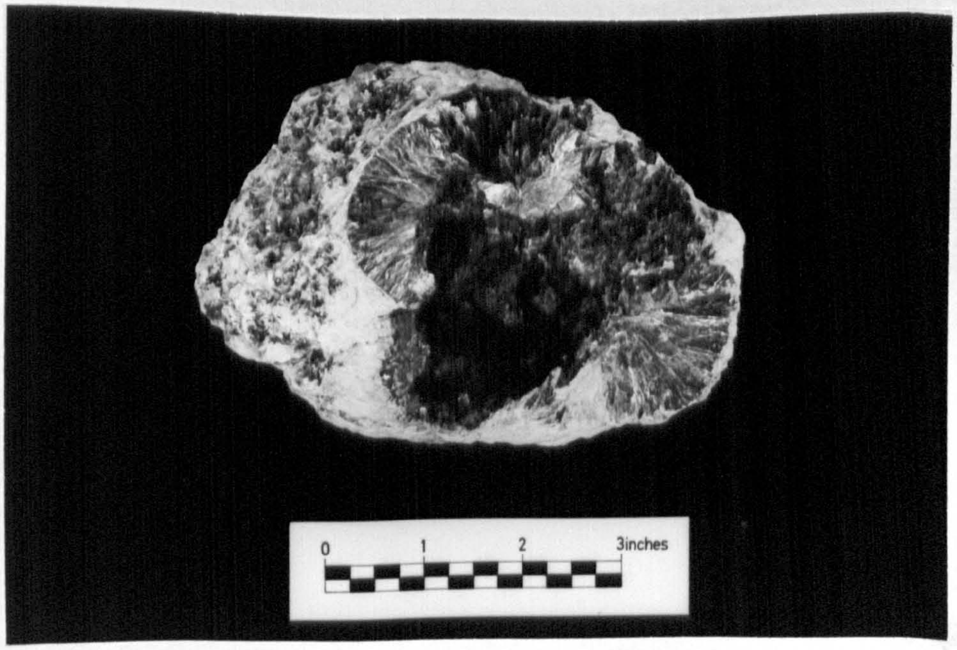


PLATE 36.
Overgrowths of green tourmaline and globular clusters of lithian muscovite on black tourmaline, Rwemeriro.

PLATE 37.
Segmented crystal of green tourmaline (verdelite) in granular core quartz, Mutaka.

feldspars.

Orthoclase feldspar

A few euhedral crystals of orthoclase feldspar approximately $\frac{1}{2}$" in diameter showing many crystal faces have been obtained from the footwall side of one of the quartz cores at Rwemeriro. The crystals occur in a matrix of cleavelandite-oncosine rock, partially replaced white microcline and pale peach-coloured garnet.

Zinc-blende and Pyrite

A small stringer of dark coloured sphalerite $\frac{1}{4}$" in thickness which contains traces of pyrite has been found in a fragment of spoil from Rwemeriro.

Group 5.

THE QUARTZ-MUSCOVITE-KAOLIN PEGMATITES

In S.W. Ankole there are a large number (36) of zoned and poorly zoned pegmatites that have been so extensively kaolinised that no trace of the original feldspars remains. These pegmatites have been classified by the writer as 'quartz-mica-kaolin' pegmatites (see table 16 , enclosures 8 ,9). ~~and appendix pp.~~ pl 38).

The internal structure of the intrusions is usually difficult to determine and many are poorly zoned and consist of a coarse intergrowth of quartz, muscovite and kaolin. The poorly zoned intrusions often have muscovite rich selvages and contain a higher proportion of quartz in their central portions than at their margins. Some fully zoned intrusions with well developed quartz cores also occur and a few of these contain, late, cross-cutting, mica rock or 'greisen' replacement units which may be columbite/tantalite bearing.

The presence of mica rock and 'greisen replacement' units in the quartz-mica-kaolin pegmatites is interesting, as it establishes a link between these pegmatites and the (related?) quartz-mica or 'greisen' veins which occur separately in S.W. Ankole and are described on pp. 69 - 76.

A few of the mica rock or greisen-bearing quartz-mica-kaolin pegmatites have been found to contain columbite-tantalite and no beryl. The absence of beryl distinguishes these from the other pegmatites of the group and they have been listed separately (see enclosure 9).

MINERALOGY

Major Minerals

Quarz, muscovite, kaolin and sericite form the bulk of the pegmatites in this group and with the exception of the quartz cores, the entire pegmatites

PLATE 38

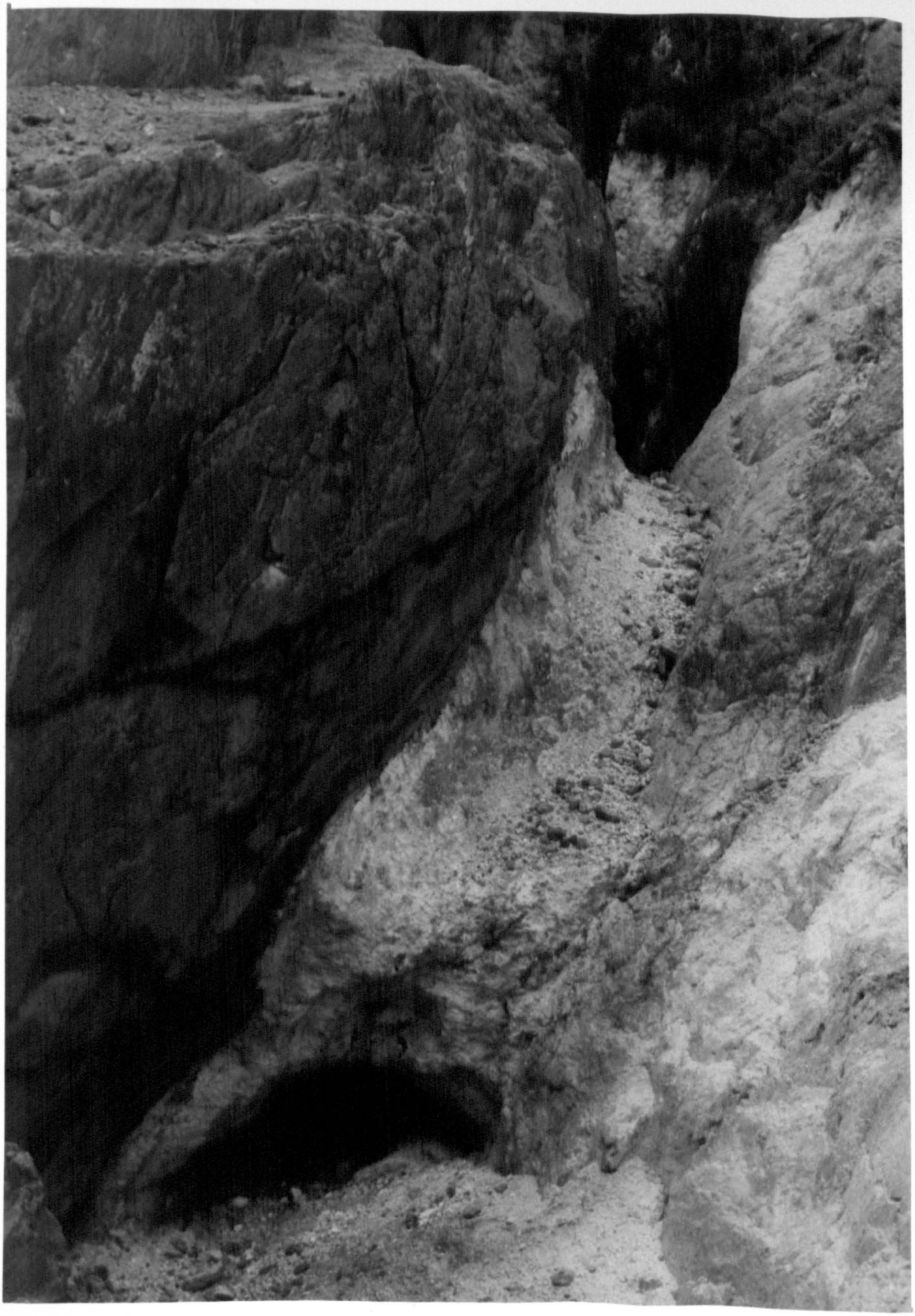


Table 16. ALPHABETICAL INDEX OF THE PEGMATITES OF GROUP 5.

Group 5a. The poorly zoned quartz-mica-kaolin pegmatites

Name	Locality No. Fig.	Name	Locality No. Fig.
KAGAMBA (Localities)	9	NYABUSHENYI, W.	8
KAKOKI I.	6	NYANGA E.	32
KAKOKI II.	6	NYANGA N.W.	32
KAKOKI III.	6	OMUKEIJENGI I (Main)	16
KAMUHA	22	OMUNGYENYI I. (West)	46
KISAKO	7	RWAMADIDI (3 prospects)	39
KISAKO N.	7	RUKUTO	11
KITOFA	57	RUTUNGURU (Beryl prospect)	10
KITOKYE (Nyanga W.)	23	RWAMAHUNGU S.	45
KYOBUGOMBE	4	RWABARAMIRA	39
MISHENYI	(45)	SHESHE	34
NYABUSHENYI S.	8		

Table 16. ALPHABETICAL INDEX OF THE PEGMATITES OF GROUP 5. cont'd.

Group 5b. The fully zoned quartz-mica kaolin pegmatites

Name	Locality No. Fig.	Name	Locality No. Fig.
KABUSANAMI (Kavusanami)	(32)	OMUKEIJENGI I. (Middle prospects)	16
KAKANENA	20	OMUKEIJENGI I. (Road location)	16
KYAMUGASHE (Columbite location)	43	RWAMAHUNGU (René prospect)	45
KYAMUGASHE (Road location)	43	RWAMAHUNGU	45
KYAMUGASHE-KAMIRA	45	BITAKA	17
NYANGA, N.E. (Ruyanza)	32		

Group 5c. The non beryl-bearing quartz-mica kaolin pegmatites

Name	Locality No. Fig.
KASHOJWA	-
RUHUMA A.	56
RUHUMA B.	56

consist of a coarse intergrowth of these minerals. A few of the pegmatites have been found to contain traces of altered microcline, but in general no feldspars remain. It is possible that some of the pegmatites contained granular albite before kaolinisation took place.

Muscovite sometimes forms discrete selvages along the margins of the pegmatites or occurs as late cross-cutting replacement (greisen-replacement) units consisting of medium grained 'green'-mica rock (plate 39). When muscovite forms selvages to the pegmatites it usually occurs as books or aggregates of books which are sometimes orientated perpendicular to the pegmatite contact.

Economic, minor and accessory minerals

Beryl

Beryl has been found in nearly all the deposits in quantities ranging from a fraction of a ton to over 35 tons (see enclosure 8,9). The beryl is usually found in association with stringers and wedges of broken quartz in a matrix of muscovite and kaolin. Where quartz cores have developed beryl occurs in large anhedral pockets adjacent to the core margins. In most of the deposits the beryl occurs mainly as friable anhedral aggregates which are ironstained yellow to deep red-brown.

Occasionally subhedral prismatic crystals of pale greenish-white, white or buff-coloured beryl occur associated with muscovite replacement and at Omukéijengi (Middle prospect) overgrowths of white beryl on earlier yellow-brown beryl have been found.

At Nyanga-Ruyanza, late-stage alteration has converted the beryl into very crumbly granular aggregates which contain numerous small flakes of muscovite.

PLATE 39.

Detail of mica rock unit containing blobs of kaolin, Kyamugashe columbite location.

Columbite-tantalite

Columbite and in particular tantalite, have been found in many of the pegmatites but large concentrations occur only in the zoned types that have also suffered 'greisen' or mica-rock replacement (Kakanena, Kyamugashe and Nyanga-Ruyanza).

At Kakanena and Nyanaga-Ruyanza, bladed crystals and aggregates of col / tantalite have been found in muscovite rock replacement units, and adjacent to the quartz cores (Kyamugashe photo 40) and large quantities have been obtained. (Over 5 tons at Nyanga up till December 1966) and 10 tons at Kakanena.

Cassiterite

Some of the pegmatites contain small quantities of black cassiterite which occur together with columbite-tantalite in mica rock or 'greisen' replacement units.

"Rose muscovite"

Small quantities of a compact pale-pink rose-muscovite rock have been found at the Ruhuma A and B pegmatites (see enclosure 9). The relationship of the rose muscovite to the surrounding pegmatite zones was impossible to establish as the pegmatites are very heavily altered and kaolinised. Small quantities of cassiterite (tiny black crystals) were found associated with the rose-muscovite rock.

Iron-manganese and manganese oxides

Traces of iron-manganese oxides are common in the quartz-mica-kaolin pegmatites and occur as dark encrustations and staining on other minerals. In some deposits (Kabusamami) iron/manganese oxide-bearing veins have been injected into the pegmatites.

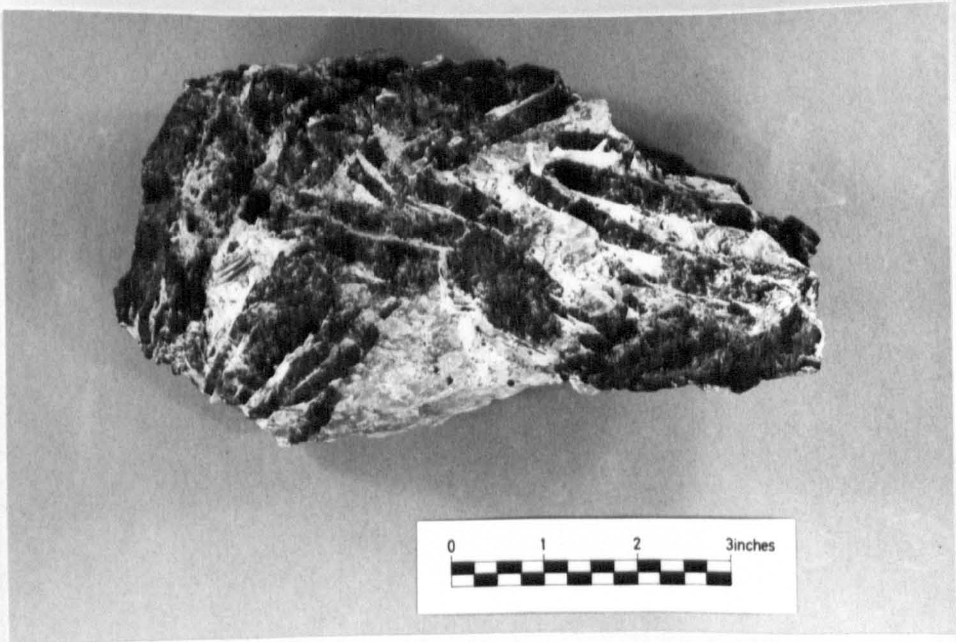


PLATE 40.
Bladed columbite in quartz, Kyamugashe columbite location.

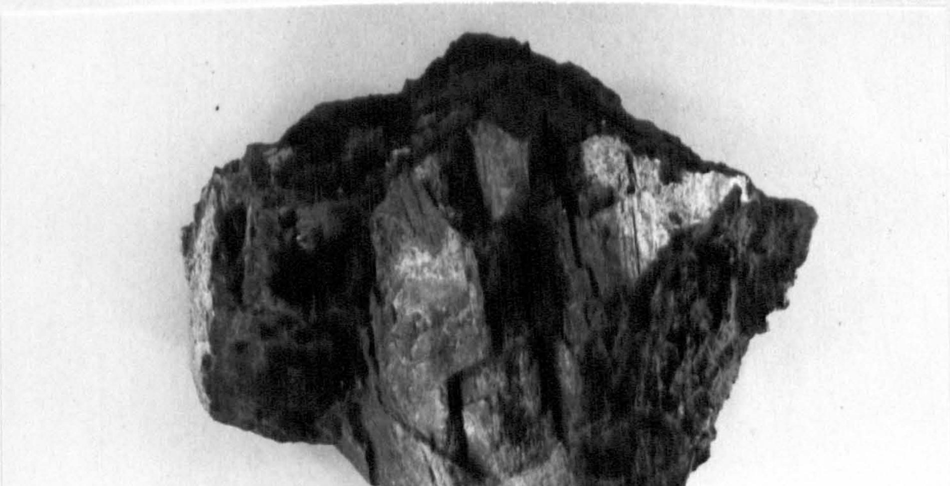


PLATE 41.
Limonite pseudomorphs after siderite, Kakanena.

Limonite

At Kakanena large boulders of limonite up to 3 feet in diameter have been found among spoil taken from the pegmatite, but none has been observed in situ. Some of the limonite has formed well developed skeletal, pseudomorphs after siderite (see plate 41).

Paragenesis of the Pegmatites of S.W. Ankole

A generalised paragenetic scheme which shows the order of crystallisation of the minerals found in the pegmatites of S.W. Ankole is presented in table 17 . The pegmatites are believed to have been formed as a result of crystallisation of injections of residual granitic magma followed by varying degrees of replacement and hydrothermal alteration.

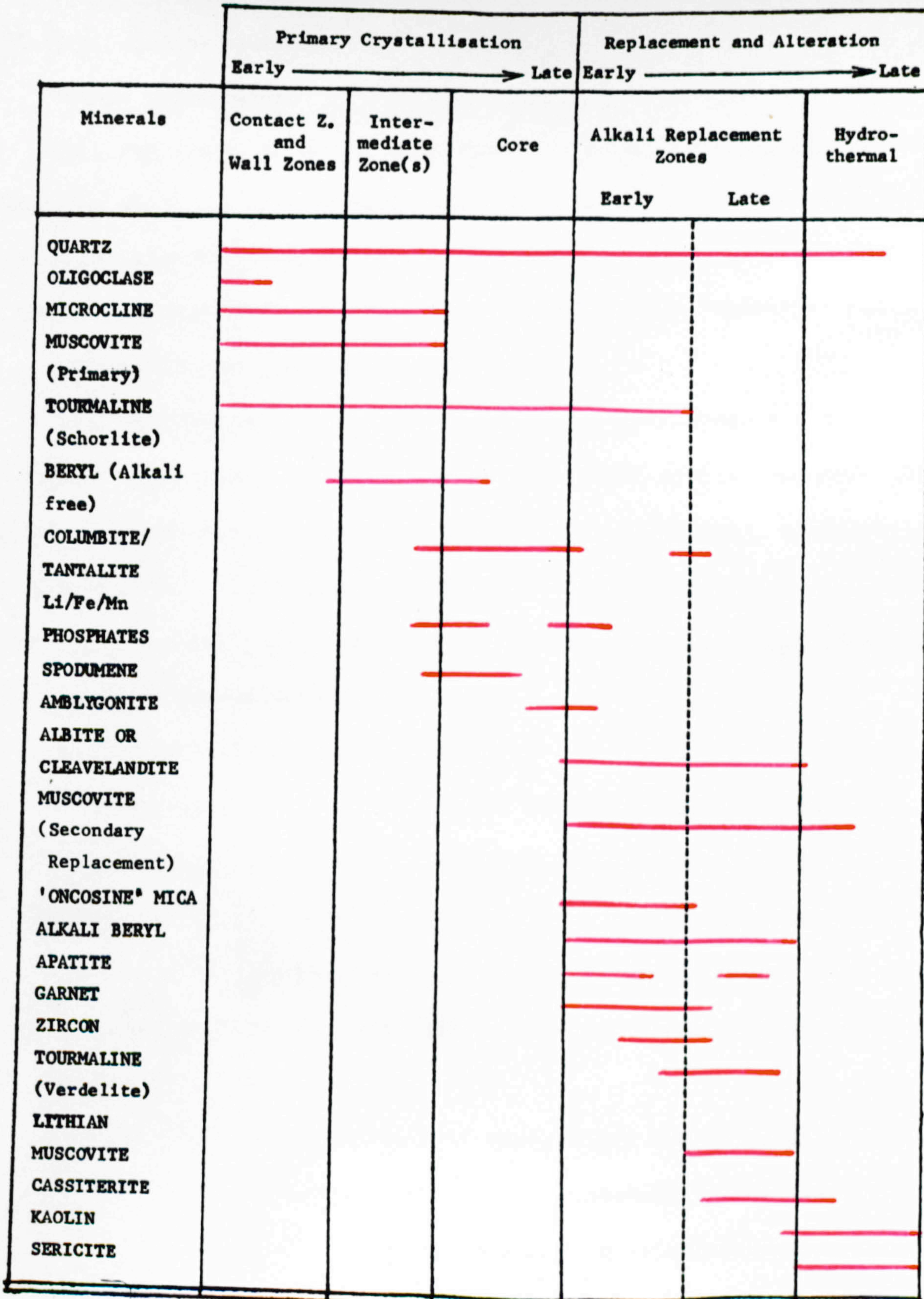
Primary crystallisation resulted in the formation of the border, wall, intermediate zones and quartz core(s) and where no further replacement or alteration occurred, produced the unaltered microcline muscovite pegmatites of groups 1a and 1c.

In some cases primary crystallisation was followed by hydrothermal alteration, kaolinisation of the feldspars and deposition of additional quartz and muscovite to produce the kaolinised microcline-muscovite pegmatites of groups 1b and 1d.

In other cases primary crystallisation was accompanied by the accumulation (or introduction) of large concentrations of alkali-bearing, volatile-rich fluids, which reacted with the primary zones of crystallisation to form extensive replacement zones. The result was the production of the albite-muscovite, spodumene-albite, and lithian muscovite-albite replaced pegmatites. In the majority of these pegmatites (in S.W. Ankole), replacement was accompanied or followed by extensive hydrothermal alteration to produce kaolinised representatives of the groups. Sometimes kaolinisation appears to have been sufficiently intense to obliterate most of the original zonal structure and later replacement zones, and has resulted in the formation of the quartz-mica-kaolin pegmatites.

Table 17.

Paragenesis of the Pegmatites of S.W. Ankole



Three different types of replacement have been recognised in the pegmatites of S.W. Ankole.

a) Sodium replacement

This has resulted in the formation of the muscovite-albite replaced pegmatites which contain abundant muscovite, cleavelandite feldspar and substantial quantities of alkali(sodium) beryl. Other minerals formed as a result of replacement include - garnet, apatite and 'oncosine' mica.

b) Sodium-lithium replacement - Type 1.

This has resulted in the formation of the kaolinised (in S.W. Ankole) spodumene-albite replaced pegmatites which contain albite, abundant muscovite, and the lithium bearing minerals - spodumene (now altered), lithiophilite and amblygonite. Substantial quantities of alkali-beryl, and columbite-tantalite and minor quantities of apatite and cassiterite were also formed as a result of the replacement.

c) Sodium-lithium replacement - Type 2.

This has resulted in the formation of the lithian-muscovite-albite replaced pegmatites which contain abundant cleavelandite albite feldspar and lithian muscovite. Alkali beryl (several varieties), columbite-tantalite and a large number of other pegmatite minerals were also formed, including 'oncosine' mica, verdelite tourmaline, garnet, manganoan apatites and cassiterite.

The two types of sodium-lithium replacement are quite distinct and in S.W. Ankole have not been found to occur together in the same pegmatite.

Type 1 is characterised by the presence of lithium bearing phosphate minerals (i.e. amblygonite and lithiophilite), whereas Type 2 is characterised by the occurrence of lithian muscovites instead.

In both cases the lithium bearing replacement minerals occur in addition to highly kaolinised spodumene laths. Chemical analyses (O. von Knorring 1968 - personal communication), show that the altered spodumene laths no longer contain any lithium and the writer suggests that alteration of the spodumene laths may have released (and made available) at least some of the lithium necessary for the formation of the lithium minerals during late stage replacement. In the lithian-muscovite-albite replaced pegmatites the lithian muscovite was certainly formed during the final stages of replacement at a time when hydrothermal alteration of the spodumene laths is very likely to have occurred.

Explanation of the zoning, replacement and hydrothermal alteration in the pegmatites of S.W. Ankole

Three possibilities have been advanced to explain zoning in complex pegmatites.

One explanation holds that the zonal structure is formed by fractional crystallisation in place under disequilibrium conditions, when reaction between crystals and rest liquid would be incomplete, creating successive layers of contrasting composition (Brögger 1890, p.230). Crystallisation within a partially closed system undergoing repeated pressure releases, and consequent resurgent boiling may account for the transgressions of younger zones upon older ones in pegmatite.

A second explanation for zoning suggests that progressively changing solutions deposit materials along the walls of open channels (Hunt, 1871). This hypothesis does not depend upon crystal fractionation and conditions of disequilibrium. The pegmatitic fluids would be expected to vary in composition for any number of reasons, such as magmatic differentiation at the source and contamination with wall rocks or other fluids in transit.

The third hypothesis suggests that complex pegmatites are developed in two stages:

1. formation of a simple pegmatite by direct crystallisation of a pegmatitic fluid,
2. partial or complete replacement of the pegmatite as hydrothermal solutions pass through it (Hanley et.al., 1950; Cotelo Neiva, 1954). The first stage is thought to take place within a relatively closed system; the second, in an open system.

Most modern workers agree with either the first or the third hypothesis or with some combination of the two (Schaller, 1933; Landes, 1933; Dery, 1931; Cameron et.al., 1949).

The writer believes that the first and third hypotheses can be applied to the pegmatites of S.W. Ankole.

The unaltered microcline-muscovite pegmatites of groups 1a and 1c and the unaltered representatives of the muscovite-albite and lithian-muscovite-albite replaced pegmatites of group 2 and 4, are believed to have formed by fractional crystallisation in place under disequilibrium conditions. The feldspars are fresh, and the zones have clearly developed from the wall inwards within a restricted system. The central zones are the youngest and replacement has occurred as a result of reaction of late pegmatitic fluids within the earlier zones of crystallisation.

The altered and kaolinised microcline muscovite pegmatites of groups 1b and 1d, the kaolinised spodumene or lithian-muscovite-albite replaced pegmatites of groups 3 and 4, and the quartz-mica-kaolin pegmatites of group 5, are believed to have formed in two stages i.e. by direct crystallisation and replacement in a closed system followed by kaolinisation under relatively open system conditions by the passage of hydrothermal fluids. In these pegmatites replacement and kaolinisation are not confined to the central portions and some of the intrusions are kaolinised and mineralised at their contacts as well as at their core margins.

These pegmatites often contain late cross cutting quartz stringers, mica stringers and mica rock units which in some cases have been found to extend beyond the margins and extend into the surrounding country rocks.

It is believed that in many cases influx of hydrothermal fluids occurred along the most convenient channelways within the pegmatites i.e. along the core margins and country rock contacts (see also Barnes, J.W. and Meal, P.F. 1959, Unpubl. Bull. 4. Uganda Geol. Surv.), and in these pegmatites muscovite replacement selvages have been found to occur along the core margins and at their contacts with the country rocks.

Resurgence of energy in the source 'magma' of the pegmatites is thought to have resulted in the introduction of the hydrothermal fluids into the pegmatites and the kaolinised pegmatites have all been found to occur where conditions are likely to have been particularly favourable for the accumulation of hydrothermal fluids; i.e. in the marginal portions of the granitic rocks and in the adjacent K-A sediments. The late hydrothermal phases which resulted in the kaolinisation of the pegmatites in Ankole are believed to be related to those which produced the quartz-mica and the hydrothermal quartz veins.

ECONOMIC ASPECTS OF THE PEGMATITES

The pegmatites of S.W. Ankole have been found to contain economic concentrations of beryl, columbite/tantalite, cassiterite and amblygonite. Substantial quantities of these minerals have been obtained both from the pegmatites and from overburden formed as a result of their weathering. The most usual method of mining is by shallow opencasting in which the overburden is first removed followed by excavation of the pegmatite proper. In most cases this has been done very unsystematically and little attempt has been made to exploit the zonal nature of the deposits.

In a few cases, where the distribution of beryl has been very obviously localised by zoning, the miners have followed certain zones in the pegmatites without realising their geological significance.

At the Rwemeriro pegmatite the beryl-bearing cleavelandite replacement zones have been followed along the entire length of the deposit and in places have been selectively followed to a depth of over 160 feet by means of underground stopes.

From a study of the zonal structure of the pegmatites the following observations can be made on the distribution of the economic minerals

Beryl

1. Larger quantities of beryl occur in the replaced and hydrothermally altered pegmatites than in the simple unaltered pegmatites. In the unaltered pegmatites the beryl usually occurs as euhedral crystals and striated monomineralic blocks whereas in the replaced and altered pegmatites the beryl occurs as subhedral crystals, and anhedral masses which are frequently friable and contain impurities.

2a. In the poorly-zoned pegmatites the distribution of beryl is most irregular, and the mineral can occur sporadically in any part of the deposit.

PLATE 42.

Typical opencast pegmatite working, Rwanza-Kabira.

Beryl can only be recovered from the poorly-zoned pegmatites by complete excavation, and in most cases the low beryl content and the large volume of material that would have to be removed, renders mining unprofitable.

2b. In the well-zoned pegmatites beryl usually occurs in greatest quantity close to the quartz core footwall margin. Distribution along the core margins is however never uniform and the beryl tends to occur in isolated pockets.

3. In the replaced pegmatites abundant beryl usually occurs scattered throughout the replacement zones but also tends to concentrate at the zone margins particularly where these lie adjacent to the quartz core. In the hydrothermally altered pegmatites kaolinisation usually obscures the limits of the replacement zones making it difficult to delimit the zones likely to contain beryl.

Columbite - tantalite

1a. The poorly zoned pegmatites do not contain economic concentrations of columbite-tantalite.

1b. In the zoned pegmatites the columbite-tantalite is usually found to have concentrated at or very close to the quartz core margins.

2. The hydrothermally altered and replaced pegmatites have been found to contain more columbite/tantalite than their unaltered equivalents.

3. In the altered and replaced pegmatites, columbite-tantalite is usually found adjacent to the quartz core and other masses of quartz, or in highly kaolinised portions of the replacement zones. It also occurs intimately associated with late muscovite-rock replacement units.

Amblygonite

In the few pegmatites that have been found to contain amblygonite the mineral occurs as large nodules along the margins of the quartz core.

Cassiterite

Cassiterite sometimes occurs in economic concentrations in the complex zoned pegmatites that have been subjected to albite, lithian muscovite-albite or 'greisen' (mica rock) replacement. The cassiterite then occurs in late-stage replacement units in association with albite, lithian muscovite or green mica-rock.

CHAPTER II

THE QUARTZ-MICA CASSITERITE BEARING VEINS

QUARTZ-MICA CASSITERITE-BEARING VEINS

Occurrence and distribution

In S.W. Ankole there are a considerable number of mineral deposits that are very difficult to classify which have features common to both quartz-mica-kaolin replaced pegmatites and hydrothermal quartz veins.

These deposits have been called quartz-mica cassiterite-bearing veins and include several which were originally described as 'mica-veins' by A.D. Combe (1932) pp. 142 - 155.

Over a dozen cassiterite-bearing quartz-mica veins have been studied by the writer (see table 18 , and enclosure 10), and all have been found to occur in K-A country rocks which lie either adjacent to the arena granites or in the synclinal schist belts which separate them (see fig. 6).

The quartz-mica veins occur closer to known exposures of granite than the hydrothermal quartz veins but unlike the granite pegmatites they have not been found to occur within granite. The quartz-mica veins are related to both the granite pegmatites and the hydrothermal quartz veins and show features common to both deposit types. Some of the quartz-mica veins contain kaolin derived by alteration of feldspar, and show similar texture and zoning to the hydrothermally altered quartz-mica-kaolin granite pegmatites, whereas others consist of simple central quartz units flanked by mica selvages and are similar in structure to the hydrothermal quartz veins.

Description

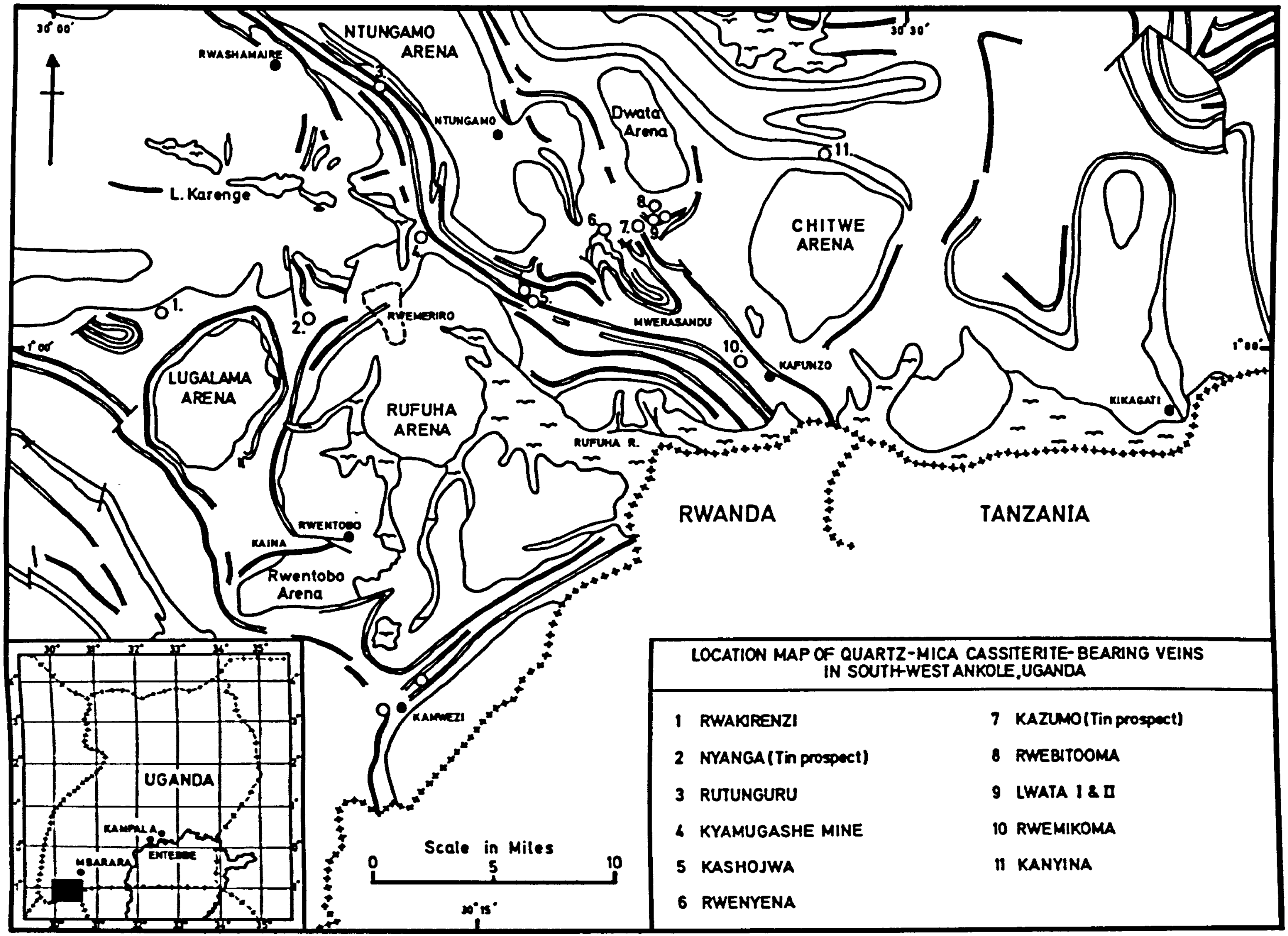
The quartz mica veins which are usually fairly narrow (1-16 feet in width - A.D. Combe 1932), have been intruded into schists and phyllites or schists and phyllites interbedded with massive quartzites (Lwata 1,

Table 18 .

ALPHABETICAL INDEX OF THE QUARTZ-MICA VEINS

Name	Locality No. Fig. .
KANYINA	11
KASHOJWA (Tin-columbite workings)	5
KAZUMO (Tin prospect)	7
KYAMUGASHE	4
LWATA I. (Dwata I)	9
DWATA II. (Dwata II)	9
NYANGA (Cassiterite-tantalite prospect)	2
RUTUNGURU	3
RWAKIRENZI	1
RWEBITOOMA	8
RWEMIKOMA (Lwemikoma)	10
RWENYENA	6

FIG 6


30°00′
30°30′
1°00′
30°15′
NTUNGAMO ARENA
RWASHAMAIRE
NTUNGAMO
Dwata Arena
L. Karenge
CHITWE ARENA
MWERASANDU
RWEMERIRO
KAFUNZO
LUGALAMA ARENA
RUFUHA ARENA
RUFUHA R.
KIKAGATI
RWENTOBO
KAINA
Rwentobo Arena
KAMWEZI
RWANDA
TANZANIA
UGANDA
KAMPALA
ENTEBBE
MBARARA
Scale in Miles
0
5
10
LOCATION MAP OF QUARTZ-MICA CASSITERITE-BEARING VEINS IN SOUTH-WEST ANKOLE, UGANDA
1 RWAKIRENZI
2 NYANGA (Tin prospect)
3 RUTUNGURU
4 KYAMUGASHE MINE
5 KASHOJWA
6 RWENYENA
7 KAZUMO (Tin prospect)
8 RWEBITOOMA
9 LWATA I & II
10 RWEMIKOMA
11 KANYINA

Kazumo and Rwenyena), and occur both parallel to the country rock schistosity and/or bedding, or occupy cross-cutting fissures which in quartzites may occur along joint planes. The country rocks adjacent to the quartz-mica veins are usually strongly tourmalinised and in some cases have also been muscovitised (Nyanga and Rwakirenzi).

The internal structure and mineralogy of the deposits is rather variable. The veins are usually linear or gently curved (Rwenyena) and in some cases have suffered local folding, warping and/or have been displaced by minor faulting.

Some of the veins branch or have a tendency to send off irregular offshoots with a dip and strike very different to that of the main portion. In some cases considerable movement must have taken place during injection and crystallisation as the margins of the veins are sheared or slickensided with alignment of muscovite parallel to the contacts.

The borders of many of the quartz mica veins are finer grained than the internal portions and consist of medium-grained granular quartz and abundant muscovite. The outer fine-grained zone (if present) passes rapidly inwards into a coarser grained zone which consist either of a coarse intergrowth of angular fragments of quartz and muscovite and/or medium to coarse-grained compact muscovite rock.

The central portion of the quartz mica veins is usually occupied by massive quartz in the form of a continuous vein or as discrete masses. (fig 7). The margins of the central quartz portion are not usually very sharp, and consist of a coarse intergrowth of quartz and muscovite. Small quantities of cassiterite and/or columbite-tantalite have been obtained from along the quartz margins but the quartz itself is usually barren.

DIAGRAMMATIC SECTIONS OF TYPICAL QUARTZ-MICA VEINS.

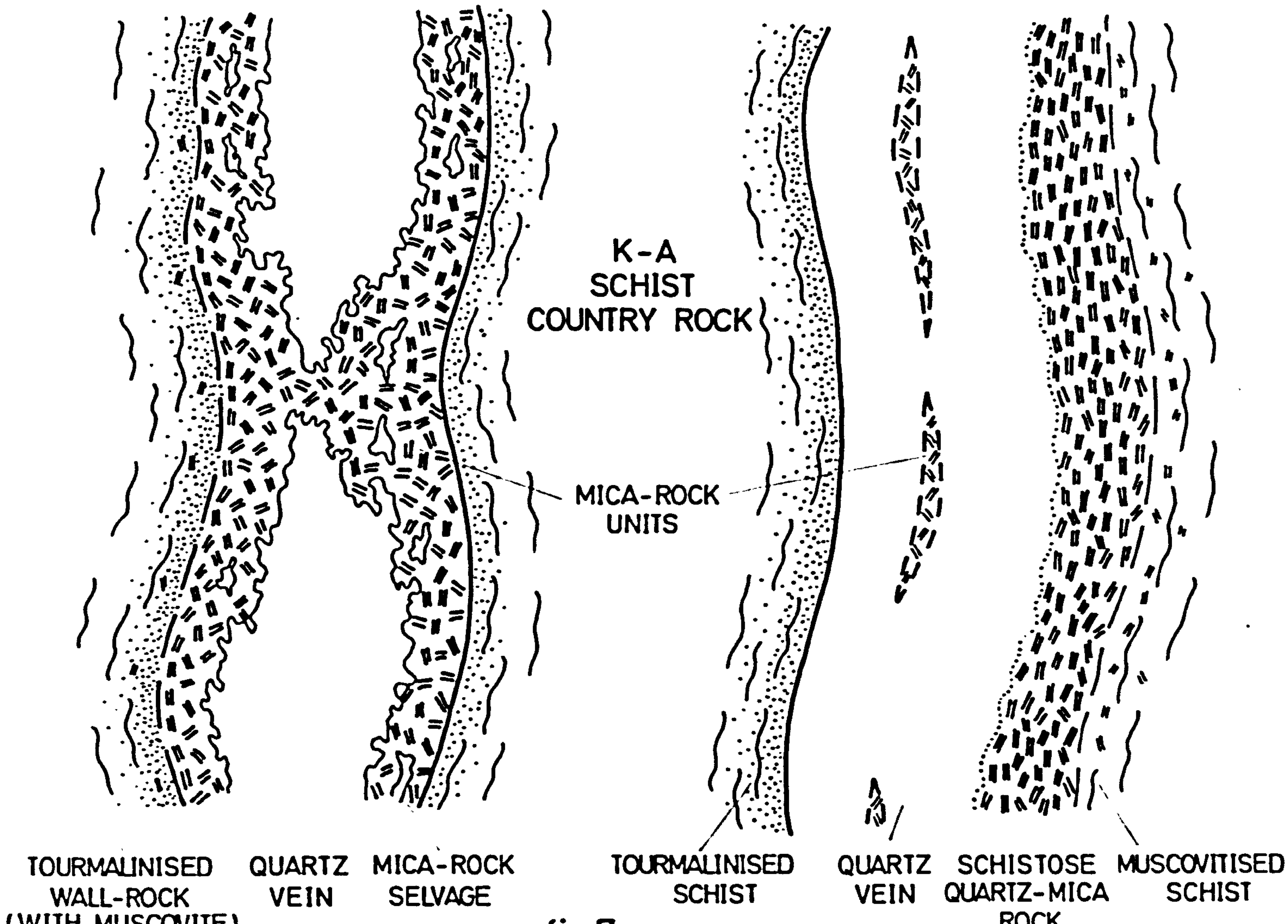


fig 7

Mineralogy of the Quartz-Mica Veins

1. Quartz

Massive transparent to translucent, colourless to milky white quartz occupies the central portions of all the deposits.

2. Muscovite

The muscovite in the quartz-mica veins is always a characteristic greenish-yellow colour (except when weathered or ironstained) and contains a large proportion of the ore minerals in the deposits. In a few of the deposits (Rutunguru), there are inclusions of muscovitised and sheared schist in the mica rock units.

3. Kaolin

Pockets of kaolin often occur in the veins, and kaolin also forms a matrix interstitial to quartz and muscovite. The kaolin may contain a high proportion of fine-grained sericite mica and pockets of brown clay have been found together with kaolin.

The kaolin tends to accumulate in pockets adjacent to the footwall side of the central portions of the veins but small patches of kaolin are frequently found totally enclosed by aggregates of muscovite. It is usually impossible to determine the origin of the kaolin although it is believed to have formed as a result of hydrothermal alteration of feldspars. No recognisable feldspars have however been found in any of the veins.

4. Tourmaline

Tourmaline is rare in the quartz-mica veins but does occur abundantly in the adjoining country rocks. Where intrusion of the veins has been accompanied by muscovitisation of the wall rocks, small quantities of tourmaline may be found in the mica rock formed from the wall rocks.

5. Cassiterite

Cassiterite is a common accessory mineral in all the quartz mica veins and is usually black or very dark brown in colour. It takes the form of small grains, crystals, irregular blebs and anhedral masses up to one or two inches in diameter. The cassiterite occurs either between muscovite and quartz or, completely enclosed in muscovite. Sometimes threads of muscovite penetrate or cross-cut the cassiterite indicating that formation of muscovite continued after deposition of the cassiterite. Occasionally quartz penetrates the cassiterite and is moulded over the crystal faces and this quartz is later in formation.

The distribution of cassiterite in the veins is irregular and it rarely occurs at the margins or in the central portion. Deposition of cassiterite has often been found to be confined to sharply defined 'pay shoots' and these are sometimes located where there is a sudden change in dip of the veins (e.g. Kyamugashe see fig. 8).

6. Columbite-Tantalite

Columbite tantalite occurs sparingly in some of the cassiterite-bearing quartz mica veins and shows the same relationship to the enclosing minerals as cassiterite. The columbite-tantalite tends to form blades or radiating conical aggregates up to 2" in length. Minor quantities are sometimes found at the margins of the central quartz units of the veins.

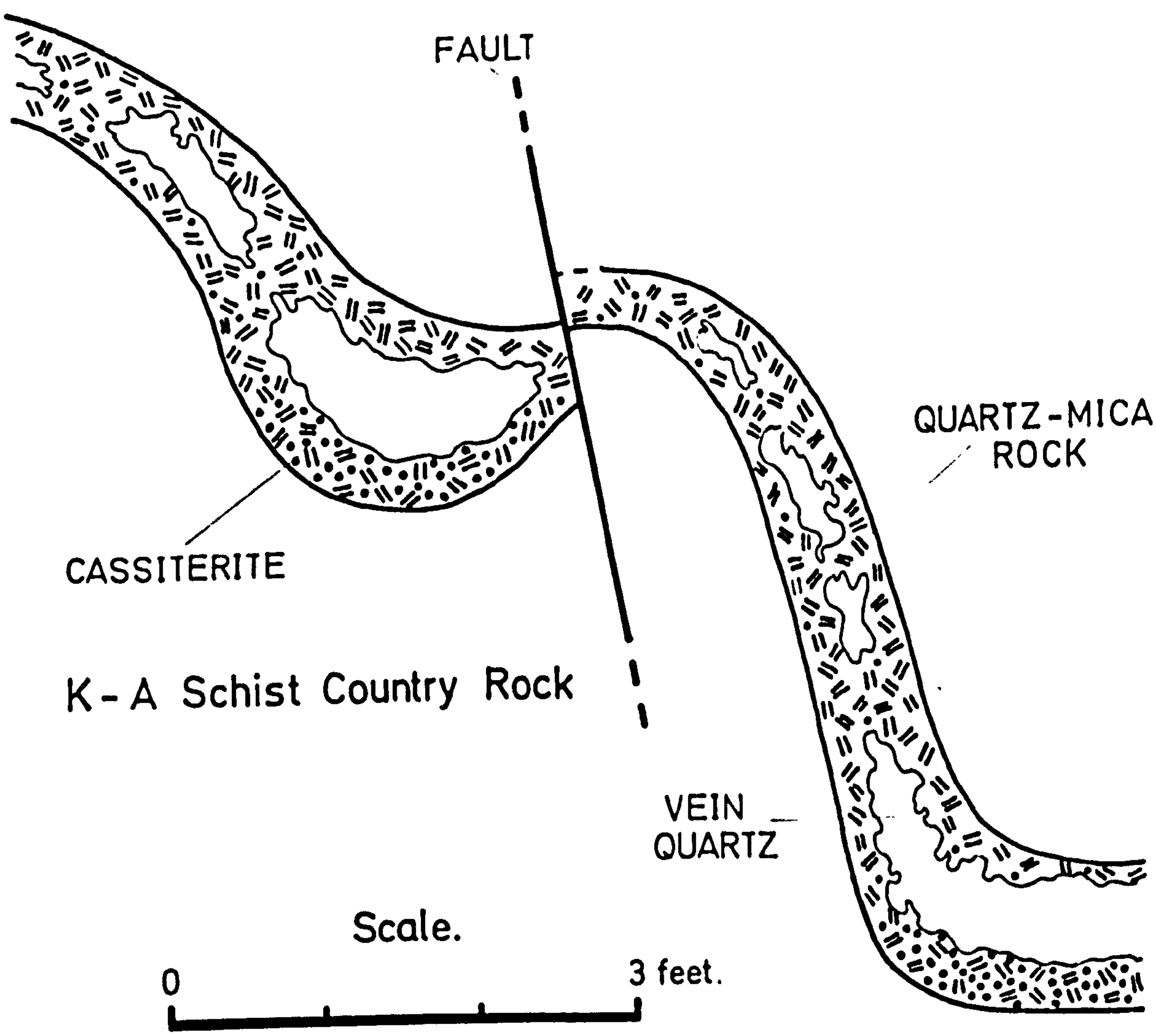
7. Beryl

Beryl is conspicuously absent from most of the quartz-mica veins but traces have been reported from the Kyamugashe veins (A.D. Combe 1936. Unpublished report of the U.G.S. 129/II No.41).

At Kyamugashe the beryl is stained pink and occurs as scattered

FIG 8

SCHEMATIC SECTION OF PART OF THE KYAMUGASHE QUARTZ-MICA VEIN SHOWING THE CONCENTRATION OF CASSITERITE IN FLAT-LYING PORTIONS.



grains and crystalline aggregates up to 1" in diameter. It is usually associated with muscovite and occasional grains of cassiterite have been found within the broken aggregates of beryl indicating that the beryl is later in formation.

8. Amblygonite

Amblygonite has been found at Rutunguru but none can now be observed in situ. It occurred as giant nodules up to 6 feet in diameter which were situated in a line parallel to but a short distance from the main quartz unit of the deposit. Amblygonite is also reported to have been obtained from the Rwemikoma deposit. (A.D. Combe 1946. Unpublished Report of the U.G.S. 129/IV No.120).

9. Manganese Oxides

Manganese oxides are found in the Kyamugashe veins and occur as thin films along the cleavages of muscovite or as encrustations on cassiterite and columbite-tantalite.

Paragenesis of the quartz-mica tin-veins

Tourmaline was the earliest mineral to be formed in association with the quartz-mica tin veins and boron metasomatism of the country rocks preceded injection of the veins and resulted in heavy tourmalinisation of the wall rocks. Injection of fluids rich in silica and volatiles then resulted in the formation of the veins containing quartz, muscovite, and feldspars which were then kaolinised. Crystallisation is believed to have occurred from the margins inwards and replacement of the country rocks by muscovite has occurred at the margins of some of the veins.

At some stage during consolidation - possibly prior to final consolidation of the central quartz unit, cassiterite and columbite-tantalite were deposited in the quartz/muscovite ("greisen") units of the veins.

Deposition of cassiterite appears to have been controlled by a number of factors which tended to localise the ore into rich pay shoots and these include sharp changes in dip of the veins. Following the deposition of cassiterite and columbite-tantalite, small quantities of beryl were formed in the veins at Kyamugashe. The time of formation of the amblygonite which occurs at Rutunguru and Rwemikoma is not known.

In some cases the structure of the quartz mica deposits indicates that there may have been more than one successive wave of injection and consolidation of material and these deposits have a more complex paragenesis, (Rutunguru).

The possibility cannot be ruled out that some of the quartz mica veins like the related quartz mica-kaolin pegmatites, may have suffered late stage replacement and hydrothermal alteration as a result of influx of late hydrothermal fluids. The highly altered nature of the quartz mica veins makes it very difficult to decipher the true history of formation.

Relationship of the quartz-mica veins to other deposit types

One of the most characteristic features of the quartz-mica tin veins is their content of "greenish yellow" mica rock. This mica rock strongly resembles that often found as late units within the replaced and altered granite pegmatitics.

In the quartz mica veins the mica rock is cassiterite and columbite/tantalite bearing and in the granite pegmatites the mica rock also tends to contain ore minerals. It is possible that the formation of the quartz mica veins in the K-A rocks took place under similar conditions to those prevailing in the pegmatites during the final phases of replacement and hydrothermal alteration.

The quartz-mica veins are also similar to the hydrothermal quartz-cassiterite bearing veins which are found in Ankole and will be described in the next section (see p.77).

At Mwirasando Mine some of the hydrothermal quartz veins pass laterally into quartz mica veins and some of the hydrothermal veins have developed thick mica rock or "greisen"-like selvages.

The presence of small amounts of beryl in the quartz mica veins (Kyamugashe)and in the hydrothermal quartz veins (Mwirasando, Nyamaherere, and Kaina) also provides a link between the deposit types.

A gradual transition from true quartz-mica veins to hydrothermal quartz veins occurs among the tin deposits of S.W. Ankole and a clear classification of any one deposit into one or the other groups is often difficult or impossible.

Kaolin content can also be used as a distinguishing feature between the two deposit types. As a rule the quartz-mica veins contain much more kaolin than the hydrothermal quartz veins although at Mwirasando Mine and Nyamaherere pockets of kaolin have been found in quartz veins.

A major difference between the quartz mica and hydrothermal quartz veins is on the colour of the cassiterite that they contain. In the quartz mica veins the cassiterite is always dark black or very dark in colour and tends to form small grains, crystals and subhedral masses. The cassiterite from the hydrothermal veins is almost invariably pale brown, reddish brown or grey brown in colour and tends to occur in much larger masses and aggregates which at Mwirasando sometimes weigh several tons each.

Unpublished work by N. Wilson, leader of the U.K. Ministry of Overseas Development Tin Exploration Team in Uganda (personal communication -

October 1968), has shown that the black cassiterites from the quartz-mica veins contain higher concentrations of niobium (0.05 to 1.1%) and tantalum (0.3 to 3.3%) than the brown and light-coloured cassiterites from the hydrothermal quartz veins which contain a maximum of 0.07% niobium and $<$0.02% tantalum.

CHAPTER III

THE HYDROTHERMAL QUARTZ-CASSITERITE-BEARING VEINS

*HYDROTHERMAL QUARTZ-CASSITERITE-BEARING VEINS

Occurrence and Distribution

Numerous hydrothermal* quartz cassiterite-bearing veins have been found in S.W. Ankole, and all occur in tourmalinised K-A country rocks which lie either adjacent to the arena granites or in the synclinal schist belts which separate them (see fig. 9). The hydrothermal veins tend to occur at greater distances from known exposures of granite than any other deposit type (i.e. pegmatites and quartz-mica veins), but some have been found situated close to granite (Murongo-Tanzania). Although no direct transition from pegmatites to quartz-mica veins and hydrothermal quartz veins has been observed in S.W. Ankole, a spatial distribution of deposits in relation to the arena granites similar to that described by Varlamoff, N. (1958) has been recognised. Approximately 20 hydrothermal deposits have been studied by the writer and these are listed in table 19 .

Description

The hydrothermal quartz-cassiterite-bearing veins of S.W. Ankole were originally described by A.D. Combe (1932) and H.A. Stheeman (1932) and are composed mainly of quartz and contain variable quantities of muscovite and sericite. The veins are very variable in shape and structure and include linear veins, tabular masses, lenses, irregular bodies and ramifying networks of stringers and veins. The shape of the quartz veins is dependent on the

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Footnote: *The term hydrothermal is here used to imply that the tin deposits were formed at a late stage of igneous activity at a later time and hence a lower temperature than the pegmatites and quartz-mica veins.

The quartz cassiterite bearing veins are believed by the writer to be hypothermal (see p. 84.) and to have originated at temperatures in the range 300-350°C.

FIG 9

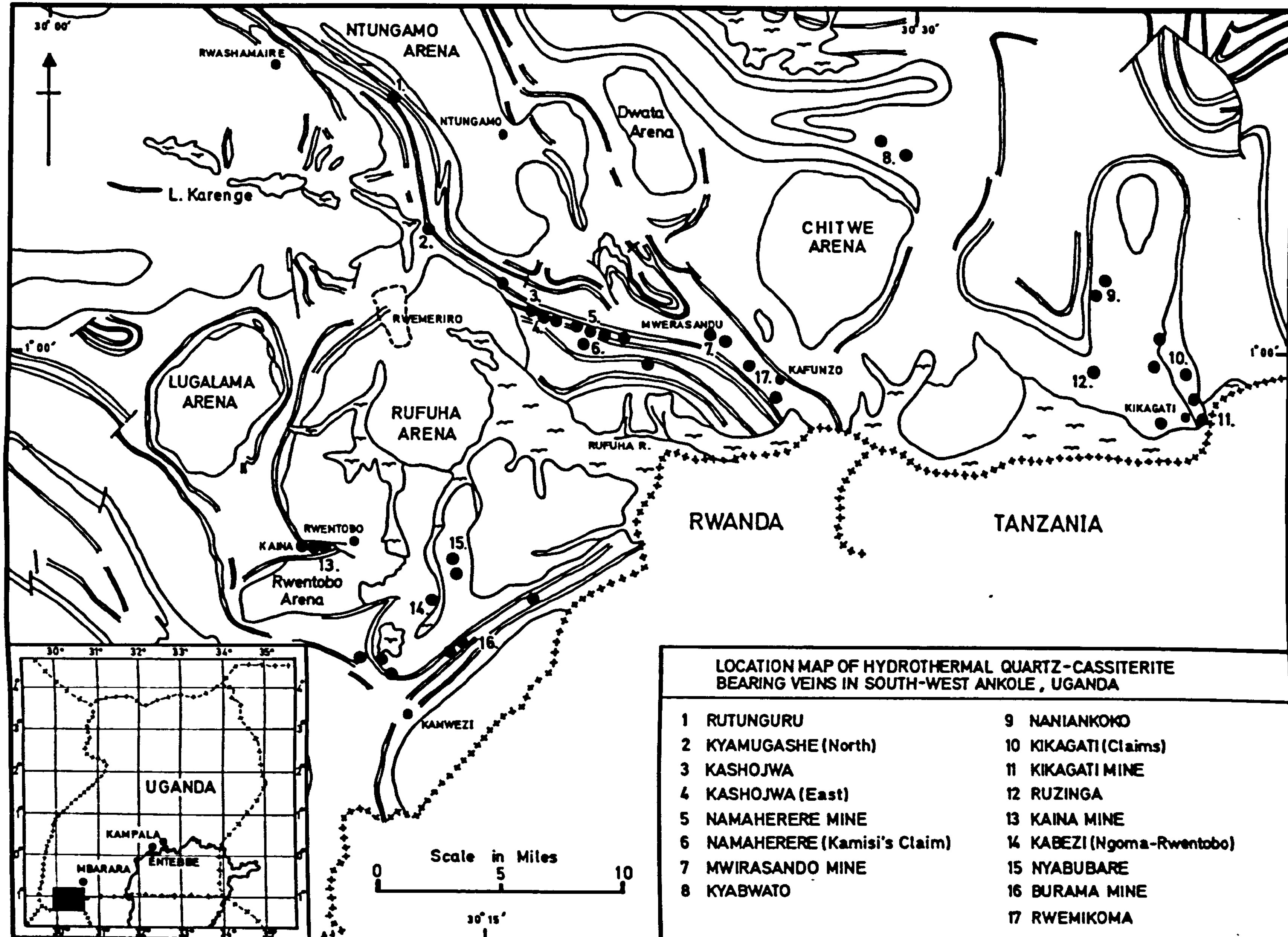

30° 00'
30° 30'
1° 00'
30° 15'
NTUNGAMO ARENA
RWASHAMAIRE
NTUNGAMO
Dwata Arena
L. Karenge
CHITWE ARENA
LUGALAMA ARENA
RUFUHA ARENA
RWEMERIRO
MWERASANDU
KAFUNZO
RUFUHA R.
KIKAGATI
RWENTOBO
KAINA
Rwentobo Arena
KAMWEZI
RWANDA
TANZANIA
UGANDA
KAMPALA
ENTEBBE
MBARARA
Scale in Miles
0
5
10
LOCATION MAP OF HYDROTHERMAL QUARTZ-CASSITERITE BEARING VEINS IN SOUTH-WEST ANKOLE, UGANDA
1 RUTUNGURU
2 KYAMUGASHE (North)
3 KASHOJWA
4 KASHOJWA (East)
5 NAMAHERERE MINE
6 NAMAHERERE (Kamisi's Claim)
7 MWIRASANDO MINE
8 KYABWATO
9 NANIANKOKO
10 KIKAGATI (Claims)
11 KIKAGATI MINE
12 RUZINGA
13 KAINA MINE
14 KABEZI (Ngoma-Rwentobo)
15 NYABUBARE
16 BURAMA MINE
17 RWEMIKOMA

TABLE 19. ALPHABETICAL INDEX OF THE HYDROTHERMAL QUARTZ-CASSITERITE BEARING VEINS

Name of Location	Locality No.*	Map Reference Sheet No.	Map Reference Co-ordinates	Unpublished Reports
Burama Ridge	16	84/1	914695	+
Burama Ridge - South	16	94/1	903673	-
Kaina	13	94/1	830770 & 827770	+
Kabezi (Ngoma-Rwentobo)	14	94/1	908727	+
Kashojwa	3	85/4	965926	+
Kashojwa (East)	4	85/4	979921	-
Kikagati (Main)	11	86/3	S.1 2' 28"	+
Kikagati (Claims 2800, 2810, 2819, 2821)	10	86/3	E.30 39' 54"	+
Kikagati (Musa's Claim 2829)	10	86/3	389874	+
Kyabwato	8	85/4	216024 & 207029	+
Kyamugashe North	2	85/3	902973	-
Muti	-	85/3	902973	-
Mwirasando	7	85/4	095905	+
Nyabubare	15	94/1	920750	+
Namaherere	5	85/4	005910	+
Namaherere (Kamisi's Claim)	6	85/4	003905	-
Rutunguru	1	85/3	878053	-
Ruzinga	12	86/3	S.1 0' 35" E.30 36' 15"	+
Rwemikoma	17	85/4	107896	+

*see fig. .

PLATE 43. (ABOVE)
Hydrothermal quartz vein, surface outcrop of No. 3 ore body at Mwirasando.

PLATE 44. (LEFT)
Hydrothermal quartz vein in quartzite, Kashojwa.

nature of the country rock and those enclosed in phyllites tend to be discontinuous, lenticular and pinch and swell erratically, whereas those occurring in quartzite and brittle country rocks occupy tension gashes, tensional openings and elongate fissures.

The size of the veins varies from massive bodies several feet in diameter and several hundreds of feet in length to small stringers barely an inch in width.

Most of the veins show a cross-cutting relationship to the country rocks and dip steeply across their dip. Occasionally bedding or schistosity has controlled the location of the veins and they have been injected concordant to the country rock structure.

A large number of the deposits terminate by pinching out either abruptly or gently. Many veins are very irregular in outline and send out offshoots into the wall rocks. Horses of country rock are not uncommon in the veins and these are usually highly altered.

Injection of the hydrothermal veins has been accompanied by movement and the veins in schist and phyllite in particular have sheared or slickensided margins with alignment of muscovite parallel to the contacts. The veins in quartzite appear to have been forcefully injected and ramifying networks of quartz are often injected along bedding and joint planes which have been displaced as a result.

A characteristic feature of all the hydrothermal deposits is the presence of abundant black tourmaline in the wall rocks (see plate 45,46). Intense boron metasomatism must have preceded injection of the hydrothermal veins and in quartzites selective tourmalinisation along bedding planes can be observed and structures not unlike bedding can be seen preserved

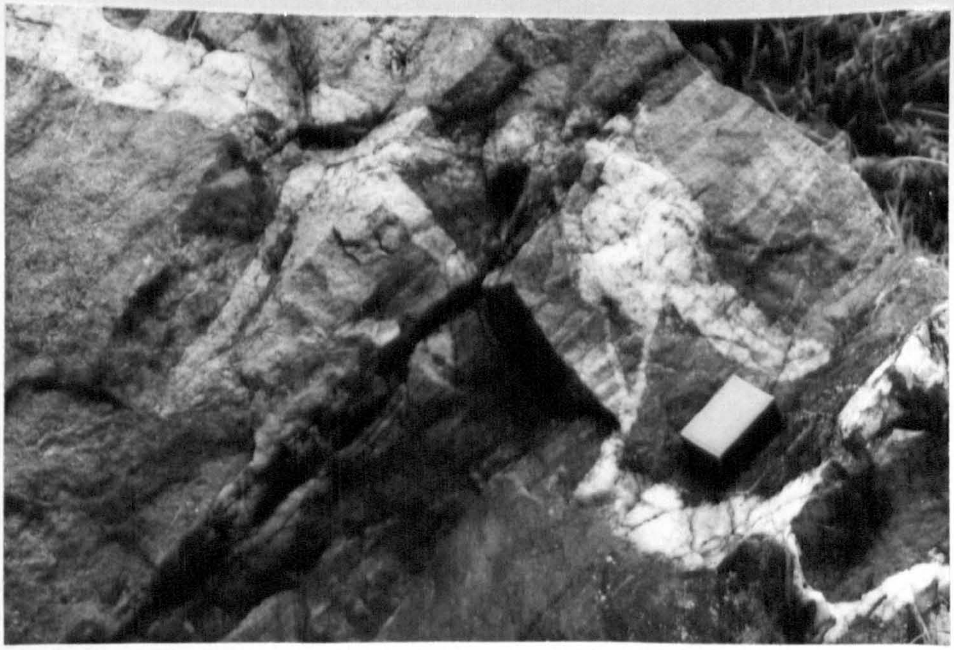


PLATE 45.
Tourmalinised quartzite with quartz veining, Burama Ridge.

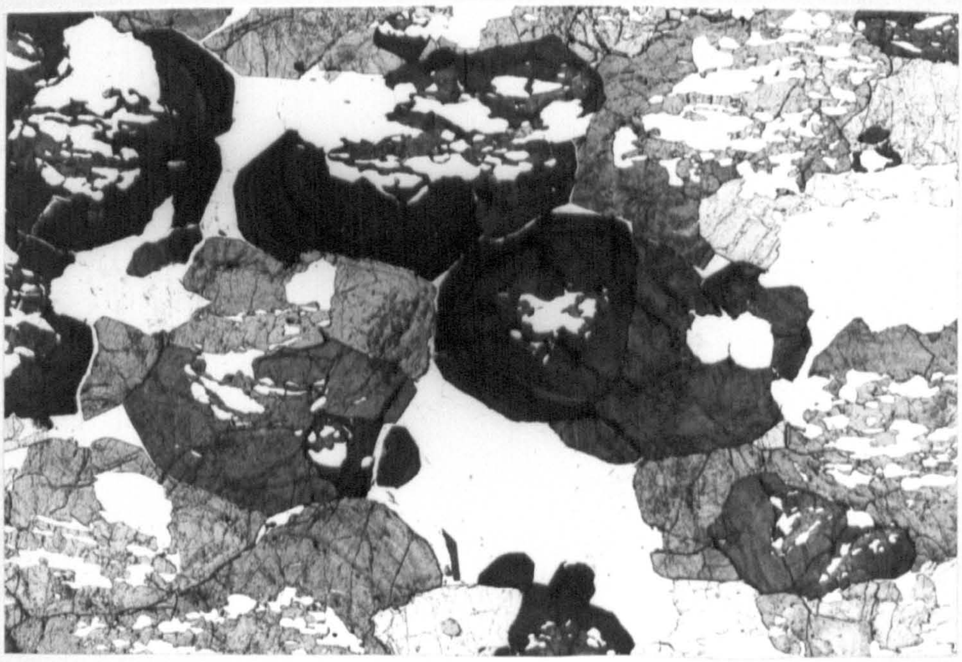


PLATE 46.
Photomicrograph showing zoned prismatic crystals of porphyroblastic tourmaline in schist country rock. Relics of original schistosity are preserved as trains of inclusions in the tourmaline.

Mag x 25

in the form of thin bands of small black crystals of tourmaline. Close to some of the hydrothermal veins (Mwirasando) tourmalinisation has been so intense that an almost pure schorl-rock has been produced which consists of a matrix of fine-grained black tourmaline.

Tourmalinisation of schist and phyllite country rocks is usually less spectacular and the tourmaline forms porphyroblastic crystals which frequently are aligned parallel to the planes of schistosity. The alignment is not believed to be due to the presence of directed stress at the time of formation of the tourmaline as some randomly orientated porphyroblasts can always be found. The tourmaline is believed to have grown preferentially along pre-existing structural planes which also acted as channelways for boron-containing fluids. Following tourmalinisation, injection of hydrothermal fluids containing silica, alkalis and volatiles resulted in the formation of hydrothermal veins in the country rocks.

The contacts of many of the veins with the country rocks is sharp but in some cases (i.e. in schists and phyllites) muscovitisation has produced muscovite-rich margins which merge gradationally into altered country rock. The injection of the hydrothermal veins into tourmalinised quartzites has led to the development of a granular texture, and recrystallisation of tourmaline which forms crystals ranging from fine acicular and stout prisms to well developed crystals up to 2" in length and ¼" in diameter along the contacts with the veins (plate 46).

The internal structure of the veins is very variable. In some cases muscovite selvages have been formed from a fraction of an inch to several feet in thickness which flank a central quartz unit. The selvages are rarely continuous, vary in thickness, and where the veins pinch the central quartz disappears and muscovite forms stringers which link the portions containing quartz. The proportion of muscovite increases at the terminations of the veins or bodies and may form solid offshoots from the main quartz units. The central portions of most of the hydrothermal veins consist of quartz which is the most abundant gangue mineral. The quartz either forms continuous dyke-like central portions to the veins or occurs as lenses and tabular masses. The quartz units may be simple or irregular in shape, some pinch and swell and others branch or send off offshoots.

Mineralogy of the hydrothermal veins

1. Quartz

Quartz is the most abundant constituent of the hydrothermal veins. The texture is variable in different deposits but it is usually colourless, blue-grey or white, and is massive, fractured, brecciated and often granular. The quartz often contains numerous fractures which are infilled by flakes, shreds and thin stringers of muscovite.

The veins may consist of large grains in a fine to medium-grained groundmass or an interlocking mosaic of quartz grains which display typical quartzitic texture. In thin section the quartz shows strain effects and in the case of quartz with a granular texture the crystals show crenulated margins and sometimes contain cracks in which there are films of muscovite.

The quartz portions of the hydrothermal veins frequently contain fractures or shear planes which are infilled with parallel aligned flakes of muscovite and these muscovite stringers usually mark channelways along which tin-bearing fluids travelled and deposited cassiterite. The mica-filled fractures frequently terminate against cassiterite which is otherwise almost entirely surrounded by granular quartz.

2. Muscovite

The muscovite of the hydrothermal veins usually takes the form of a compact aggregate of light buff, white or pale green flakes which average ¼" across. Much of the mica is associated with soft fine-grained sericite and sometimes a white kaolin-like material. Coarse flakes of muscovite have been observed by A.D. Combe (1932, p.126) "passing into fine aggregates of pearly white sericite and thence into the kaolin-like material, the whole preserving the shape of the original flake of muscovite from which it was derived".

Not all the sericite and kaolin-like material have been derived as alteration products of muscovite and substantial quantities of primary sericite may be found at Mwirasando Mine.

The muscovite selvages of the hydrothermal tin veins are very important repositories of cassiterite and the distribution of this ore will be described later (see p.82).

3. Kaolin

Kaolin is rare in the hydrothermal veins but in some of the deposits a white kaolin-like material has been found in association with muscovite and sericite. The origin of the kaolin is not certain but some is believed to be an alteration product of muscovite (A.D. Combe 1932).

Patches of kaolin and sericitic materials have also been found in association with altered beryl and in quartz at Mwirasando Mine. The possibility that some kaolin has formed by alteration of original feldspathic components of the hydrothermal veins cannot be ruled out.

4. Sericite

Sericite mica is not present in all the hydrothermal tin veins but is abundant at Kaina and Mwirasando mines. The nature of the sericite and sericitic material found varies considerably and in some cases it occurs in a white kaolin-like matrix as fine white pearly scales. Larger flakes of sericite also occur in the "kaolin" and reach a maximum of 1" in diameter. A.D. Combe (1932) proposed that the white kaolin-like material found at Mwirasando also consisted of very fine-grained sericite.

5. Tourmaline

Tourmaline is comparatively rare in the hydrothermal veins in spite of its abundance in the adjacent wall rocks. It occurs as scattered black prismatic crystals and can be found in a matrix of quartz or partially enclosed in mica and cassiterite. The abundance of tourmaline usually increases towards the margins of the veins but also occurs adjacent to inclusions of country rock.

At Kikagati Tin Mine a second late generation of fine-grained brownish tourmaline has been found and forms veins in massive quartz. The tourmaline consists of fibrous aggregates which sometimes enclose muscovite and also contain small specks of galena. The brown tourmaline appears to have been deposited at a late stage in the formation of the veins, possibly together with galena.

6. Cassiterite

Cassiterite occurs throughout the hydrothermal deposits but is usually associated with micaceous parts of the veins. Irregularities in the veins, flattenings, rolls and pinches often localise ore shoots and are a useful guide in a search for cassiterite.

The cassiterite occurs as grains, irregular blebs, nodules and anhedral masses which range in size from a fraction of an inch to several inches in diameter. At Mwirasando Mine giant anhedral masses of broken cassiterite up to 10' x 3' x 6' are said to have been found in a rich ore shoot (A.D. Combe - Unpublished report ADC/129/1/21). The larger masses of cassiterite as found at Mwirasando display smooth surfaces but most of the cassiterite is shattered and easily broken because of the presence of numerous threads of quartz and muscovite. Where cassiterite occurs in kaolin or aggregates of sericite the ore is very friable and falls to pieces easily.

One excellent specimen of solid massive cassiterite weighing 22 lbs. has been obtained from No. 10 workings at Mwirasando Mine (see plate 47). The cassiterite mass is 10" in diameter and has fractured along two flat surfaces resembling cleavage planes. Close examination of the planes shows that the mass is made up of numerous laminae of slightly differently coloured cassiterite traversed by several quartz and mica-containing veinlets which postdate crystallisation of the ore. The outer surfaces of the specimen are enveloped by a selvage of medium-grained muscovite which has the appearance of having been "wrapped" around the cassiterite.

The colour of the cassiterite from the hydrothermal tin veins varies a great deal and all shades from light-grey and lilac-grey to pale brown, ruby-red and dark brown are found. Many colours can occur in any one deposit.

At Ngoma-Kabezi and at Burama Ridge one or two deposits have been found which contain small prismatic crystals of water-clear, colourless or pale straw-coloured cassiterite. The crystals are often zoned and have dark cores overgrown with outer zones of transparent cassiterite. Their size is usually small ranging from a fraction of an inch to approximately $\frac{1}{2}$" in diameter.

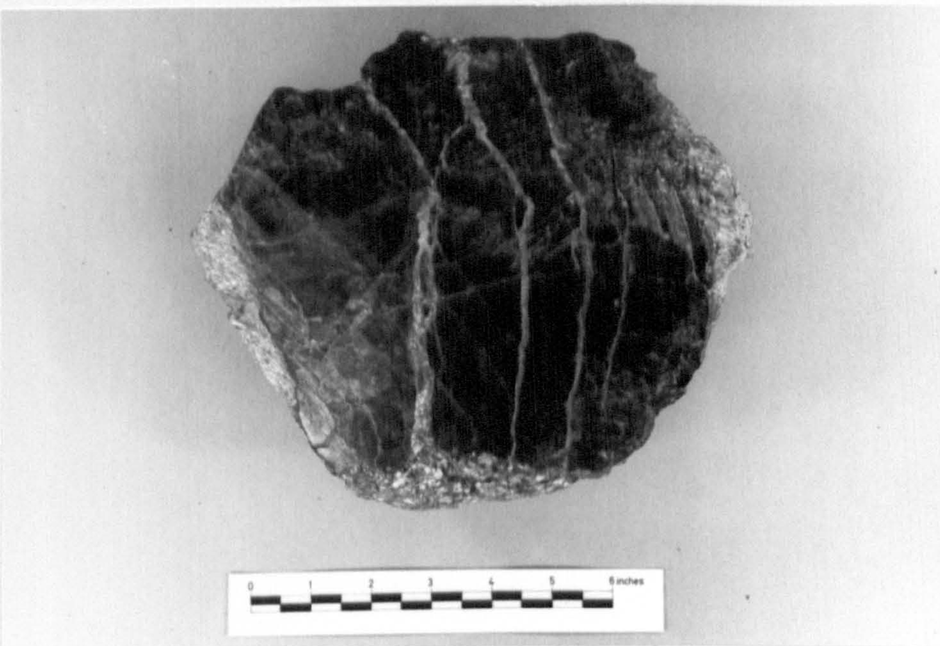


PLATE 47.

Large anhedral crystal of cassiterite from Mwirasando Mine.

Various workers including Stockley and Williams (1938) (who studied the hydrothermal deposits in the Karagwe Tinfield), have suggested that the nature of the country rock influences the colour of cassiterite in the hydrothermal deposits. The ore obtained from veins crossing schist or phyllites is claimed to be opaque and dark brown or black whilst that from quartzites is translucent amber, grey or yellowish. Cassiterite from veins in granite is reported to have intermediate colours.

The writer has not found such a sharp correlation in S.W. Uganda, and believes that other factors may also influence the colour of the cassiterite in the deposits.

Euhedral crystals of cassiterite are rare in the tin veins of S.W. Ankole but have been found at Mwirasando where tetragonal acutely bipyramidal and twinned tetragonal acutely bipyramidal crystals of dark brown to black cassiterite up to 1" in diameter occur in the mica rock units of some of the veins (see plate 48). At Kaina Mine brown elongate prismatic and twinned prismatic crystals have been found in a portion of one of the veins near the summit of Nobugamba Hill (see plate 49).

The habit of cassiterite has been shown to give a rough indication of the temperature of formation of tin deposits by Schneider, Yu.A (1937) and by Varlamoff, N. (1949).

The temperature of formation of acutely dipyramidal crystals is reported to be 450°C whereas that of columnar prismatic crystals is less than 450°C (Schneider, Yu.A. 1937). The occurrence of acutely bipyramidal crystals of cassiterite at Mwirasando suggests a temperature of formation of approximately 450°C and the columnar prismatic crystals from Kaina suggest a somewhat lower temperature i.e., below 450°C. If this is correct then the

PLATE 48.

Acutely bypyramidal twinned crystal of cassiterite,
Mwirasando Mine.

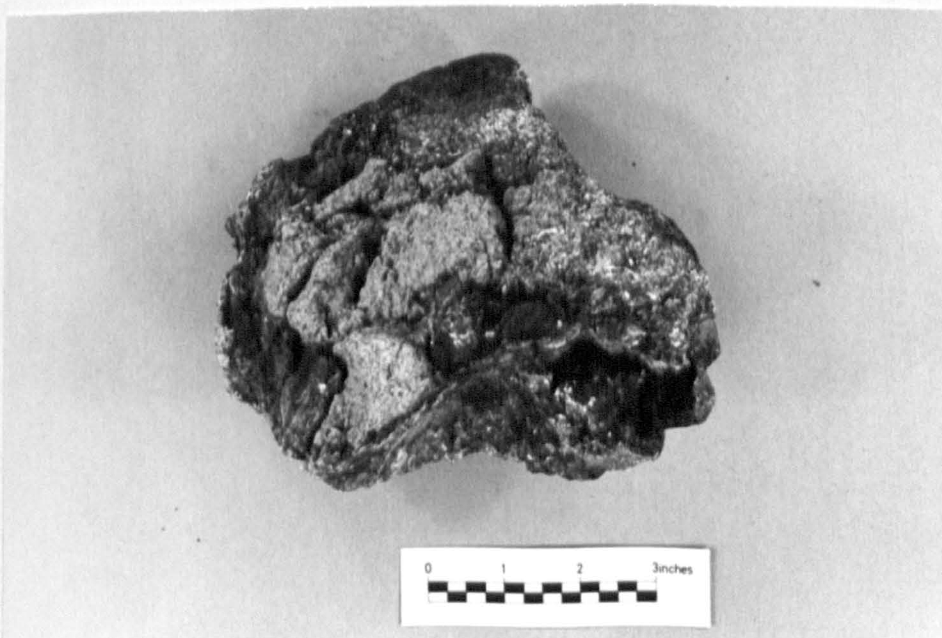


PLATE 49.

Prismatic crystals of cassiterite in matrix,
Nobugamba Hill - Kaina.

hydrothermal quartz-cassiterite bearing veins of S.W. Ankole originated in the temperature range 300 - 500°C, and are hypothermal.

7. Beryl. $Be_3Al_2Si_6O_{18}$

Beryl has been found in a number of the hydrothermal tin deposits including Nyamaherere, Mwirasando, Kaina and Ruzinga. It usually occurs in the muscovite selvages of the deposits in the form of highly shattered and ironstained anhedral aggregates. At Mwirasando large patches of broken beryl up to six feet in diameter have been found and in places the beryl occurs moulded around cassiterite and is clearly later in formation. When in situ the beryl is usually yellow-brown to rose-coloured due to iron-staining along cleavage and fracture planes but when unstained it is nearly colourless to white with a tinge of pale green.

The beryl often occurs in association with white kaolin and sericite-like material which in places penetrates fracture and cleavage planes in the beryl. At Kaina mine, small roughly hexagonal crystals of beryl have been found in the mica rock selvages.

As a rule the beryl in the tin deposits does not occur in contact with cassiterite and is often confined to separate portions of the veins.

8. Euclase. $BeAlSiO_4(OH)$

Euclase has been found in small quantities in the Nyamaherere tin deposits (Re: M.J. Gallagher and J.R. Hawkes 1966). It forms pinkish-coloured anhedral masses set in iron-impregnated beryl. The euclase occurs as aggregates and has an average grain size of 3 mm.

Beryllian Margarite. $CaAl_2(Si,Al,Be)_4O_{10}(OH)_2$

Beryllian margarite is reported by Gallagher and Hawkes (1966) to occur in the Nyamaherere tin veins and occurs in association with beryl and euclase. It forms clusters of tablets averaging 0.2 mm. across in a matrix of aggregates of muscovite (flakes up to 3 mm. in length), finely-divided mica, hematite-coated quartz grains (up to 2 cm. across) and accessory rutile.

9. Sulphides

Sulphides are generally rare in the hydrothermal tin deposits of S.W. Ankole but traces have been found at one or two localities.

a. Galena

Galena has been found at only one locality - Kikagati Mine where it occurs as isolated stringers in quartz together with pyrite, and in minute amounts in stringers of brown tourmaline. The galena is late in formation and postdates deposition of cassiterite.

b. Pyrite

Small grains of pyrite have been found at Kikagati mine and at Nyamaherere. At Nyamaherere the pyrite forms small distorted striated pyritohedra in the vein quartz but many have been altered to form pseudomorphs of limonite after pyrite.

c. Arsenopyrite

Small quantities of arsenopyrite have been found in muscovite rock at Kikagati Mine.

10. Iron Oxides

Hematite and limonite are abundant in many of the hydrothermal veins. Stringers and veins of fine-grained iron oxides occur along fissures and joint planes in the quartz veins and at Kikagati veins of hematite have been found to cross-cut cassiterite indicating that the hematite is later in formation. Iron oxides usually post-date cassiterite in the hydrothermal veins but at Ngoma-Rwentobo deposition of cassiterite has occurred after the formation of the iron oxide stringers and colourless cassiterite sometimes occurs on a substrate of iron oxides.

11. Graphite

Small quantities of graphite have been found in the Mwirasando deposit and in tourmalinised quartzite at Kikagati. At Mwirasando the graphite is an amorphous sooty variety but fine-grained crystal aggregates also occur (A.D. Combe 1932, p.128). It forms small irregular masses and scattered grains and sometimes is present between flakes of muscovite.

At Kikagati some of the tourmalinised quartzite country rocks contain abundant very finely-divided graphite and the graphite when it occurs in the tin deposits is believed to have been derived from the country rocks.

Paragenesis of the Hydrothermal Tin Deposits

The paragenesis of the hydrothermal tin deposits has received the attention of several workers who do not entirely agree on the matter. H.A. Stheeman (1932) worked out the paragenesis of a few of the more important tin veins including the Kaina deposit. His sequence of mineral formation can be summarised as follows:-

1. Sericite (in K-A country rocks undergoing mineralisation) recrystallised to form fine scaly mica.
2. Tourmaline was deposited at the cost of sericite as well as at the cost of fine scaly mica.
3. Mica deposited - and coarse foliae were formed simultaneously with the deposition of tourmaline.
4. Deposition of tourmaline ceased and it was again resorbed by an extremely coarse mica deposited along the main channel. By this process the vein was formed.
5. Cassiterite was deposited principally in the coarse mica of the vein but also in or against the wall rock thereby embracing tourmaline.
6. Short phase of deposition of fine scaly mica at cost of cassiterite and tourmaline.
7. Topaz (mistaken identification of beryl by Stheeman - P.L.L.), deposited at expense of coarse mica.
8. Quartz deposited and replaced mica, cassiterite and tourmaline.

In Stheeman's view silicification, which occurred late, resulted in the disappearance and loss of cassiterite and mica in the deposits and he observed that more mica tended to occur in the hydrothermal deposits in aluminous rocks (sericite phyllites) than in the arenaceous phyllites of the middle division of the K-A system. He states also that deposition of coarse muscovite may have been obscured by subsequent silicification. Stheeman also believed that cassiterite generally replaced muscovite and he observed that deposits containing abundant muscovite often contained more cassiterite.

In the opinion of A.D. Combe (1932, pp. 176-178) the paragenetic sequence for the tin deposits was:

1. Tourmalinisation of the country rocks.
2. Simultaneous deposition of cassiterite and muscovite with deposition of muscovite continuing after cassiterite. (Some cassiterite also formed earlier than muscovite).
3. Deposition and crystallisation of quartz- possibly two generations. (The early phases of quartz deposition were simultaneous with the deposition of cassiterite but continued long after deposition of cassiterite).

Unfortunately no mention is made by Combe (p. 176-178) of the position of sericite in the paragenetic sequence but in his description of the minerals in the tin deposits (p. 126) he stated that "much of the muscovite is associated with a soft fine grained aggregate of a pearly mica that appears to be sericite, and a very fine kaolin-like material which may also be sericite, and in places the muscovite certainly seems to alter to white pearly sericite". Combe does however add that not all sericite is an alteration product of muscovite.

Any sericite which has been formed by alteration of muscovite (as at Mwirasando) must be placed late in the paragenetic succession.

Beryl in the Mwirasando deposits has been shown by Combe (pp. 127-128) to be later than cassiterite and he also suggests that some of it has been altered to a white kaolin like material (para. 301).

W.C. Simmons in a post-script at the end of Combe and Groves's publication summarises the paragenesis of the Mwirasando deposits slightly differently as follows:-

1. Tourmalinisation of the country rocks.
2. Formation of sericite (as found in kaolin-like aggregates in the veins).
3. Partial recrystallisation of sericite to muscovite and deposition of cassiterite. Cassiterite was deposited before, after and simultaneously with muscovite.
4. Influx of silica, completing deposition of cassiterite and final crystallisation of silica as quartz causing cementation and filling up of the vein channels with massive quartz.

Here mention is made of sericite formation but it is placed early in the paragenetic sequence. No mention is made by Simmons of the sericite which according to Combe appears to form from muscovite, and both beryl and the kaolin-like material have been omitted from the paragenetic scheme.

There is agreement however between Combe, Groves and Simmons on the position of cassiterite in the paragenesis and it is almost certain that deposition of cassiterite occurred prior to, simultaneously with, and after deposition of muscovite. The deposition of cassiterite was terminated during final crystallisation of silica to form the quartz units of the veins, and W.C. Simmons reports that some cassiterite was dissolved during deposition of the quartz.

Combe and Groves differ from H.A. Stheeman in that they do not recognise an early phase of sericite formation but Simmons in his paragenetic scheme does mention an early phase of sericite formation. Another major difference is that Combe, Groves and Simmons do not recognise large scale replacement of cassiterite, tourmaline and muscovite during the final stages of formation of the deposits. They merely suggest that a final influx of silica occurred in the deposits which resulted in the crystallisation of the quartz portions of the veins. Only minor solution and replacement of cassiterite is inferred in their work and no mention is made of replacement of muscovite by quartz.

G.M. Stockley and G.J. Williams, in Bull. No. 10. of the Tanganyika Geological Survey (1938) describe the paragenesis of the hydrothermal tin veins of the Karagwe Tin fields (which adjoin those in S.W. Ankole) and the following sequence of mineral formation can be inferred from their work:-

1. Tourmalinisation of country rocks.
2. Deposition of muscovite and cassiterite (with deposition of cassiterite simultaneously with or just after muscovite).
3. Crystallisation of quartz.

Stockley and Williams substantiate the observations of Combe, Groves, and Simmons - that tourmaline occupies an early position in the paragenesis and is rare within the deposits. If it does occur in the tin veins it occurs as small euhedra formed at a late stage by re-deposition of material absorbed by the reef solutions from the wall rocks.

Their observations also indicate that deposition of muscovite and cassiterite overlapped. Stockley and Williams state that the cassiterite in the micaceous selvages of the tin veins crystallised mainly after the mica but that in the quartz portions of the veins deposition of cassiterite was contemporaneous with that of mica.

Quartz is stated to be late and was observed to fill cracks in cassiterite. Stockley and Williams observed that resorption of cassiterite occurred along the cracks suggesting that cassiterite had been taken into solution by the late aquo-siliceous melt. This is in agreement with observations made by Simmons on material from Mwirasando.

Beryl is mentioned but its position in the paragenesis is again not stated. Stockley and Williams do however note the presence of kaolin in the Karagwe deposits. They dispute that the kaolin-like material was derived by alteration of beryl as suggested by Combe p.127 and present evidence that in Karagwe the kaolin could have been derived from feldspar (p. 75). No comment is made on the suggestion by Combe that the kaolin formed as a result of alteration of muscovite and sericite.

The question is raised as to whether a large proportion of the kaolin in the Ankole deposits is not also derived by alteration of feldspar. It is the writers opinion that in the tin deposits of S.W. Ankole, sericite or kaolin-like material has been formed as a result of alteration of muscovite and sericite <u>and</u> by the alteration of feldspars.

As a result of a survey of the literature and on evidence accumulated by the writer it is proposed to present the following general paragenetic succession for the hydrothermal tin deposits of S.W. Ankole:-

Paragenetic Succession for the Hydrothermal Quartz-Cassiterite bearing Veins of S.W. Ankole, Uganda

1. Sericite in argillaceous country rocks recrystallised to form fine scaly mica (some deposits only). Arenaceous country rocks also recrystallised.

2. Tourmaline deposited in country rocks at cost of sericite, fine scaly mica, quartz, and other constituents.

3. Mica deposition in vein channels commenced during last stages of deposition of tourmaline in country rocks.

4. Main phase of mica deposition. Coarse muscovite deposited in vein channels some resorption of tourmaline in wall rocks. (Feldspar deposited).

5. Cassiterite deposited simultaneously with or after deposition of bulk of the muscovite. In some deposits cassiterite also preceded the main phase of muscovite deposition.

6. Muscovite deposition continues in some cases until well into the main phase of quartz deposition - muscovite infills fracture planes in cassiterite.

7. Muscovite in some deposits locally altered to sericite and kaolin-like material - any feldspar present (if not already altered) converted to kaolin. Deposition of beryl.

8. Main phase of quartz deposition - crystallisation of quartz to form quartz portions of veins (frequently granular).

9. Second phase of deposition of quartz in some deposits - granular quartz (containing muscovite stringers) cemented by late quartz. Crystallisation of silica terminated deposition of muscovite and cassiterite and was accompanied by limited replacement of cassiterite by quartz.

9a. In some deposits minor quantities of sulphides were deposited prior to final consolidation of the quartz.

10. Fracture of the veins accompanied by deposition of hematite and limonite.

CHAPTER IV

RELATIONSHIP OF THE MINERAL DEPOSITS TO EACH OTHER AND TO THE GRANITIC ROCKS

Relationship of the mineral deposits to each other and to the granitic rocks.

In S.W. Ankole three major mineral deposit types have been recognised:-

1. Beryl bearing granite pegmatites
2. Quartz-mica cassiterite-bearing veins
3. Hydrothermal quartz cassiterite-bearing veins (see fig. 10)

1. Regional and field relationships

The mineral deposits show a pronounced regional zonality and the following sequence with increasing distance from the granites has been recognised.

1. Unaltered microcline-muscovite beryl-bearing pegmatites. (Interior pegmatites which occur within the granitic rocks and migmatites).

2a. Kaolinised microcline-muscovite pegmatites

b. Muscovite-albite replaced pegmatites

c. Kaolinised spodumene-albite replaced pegmatites

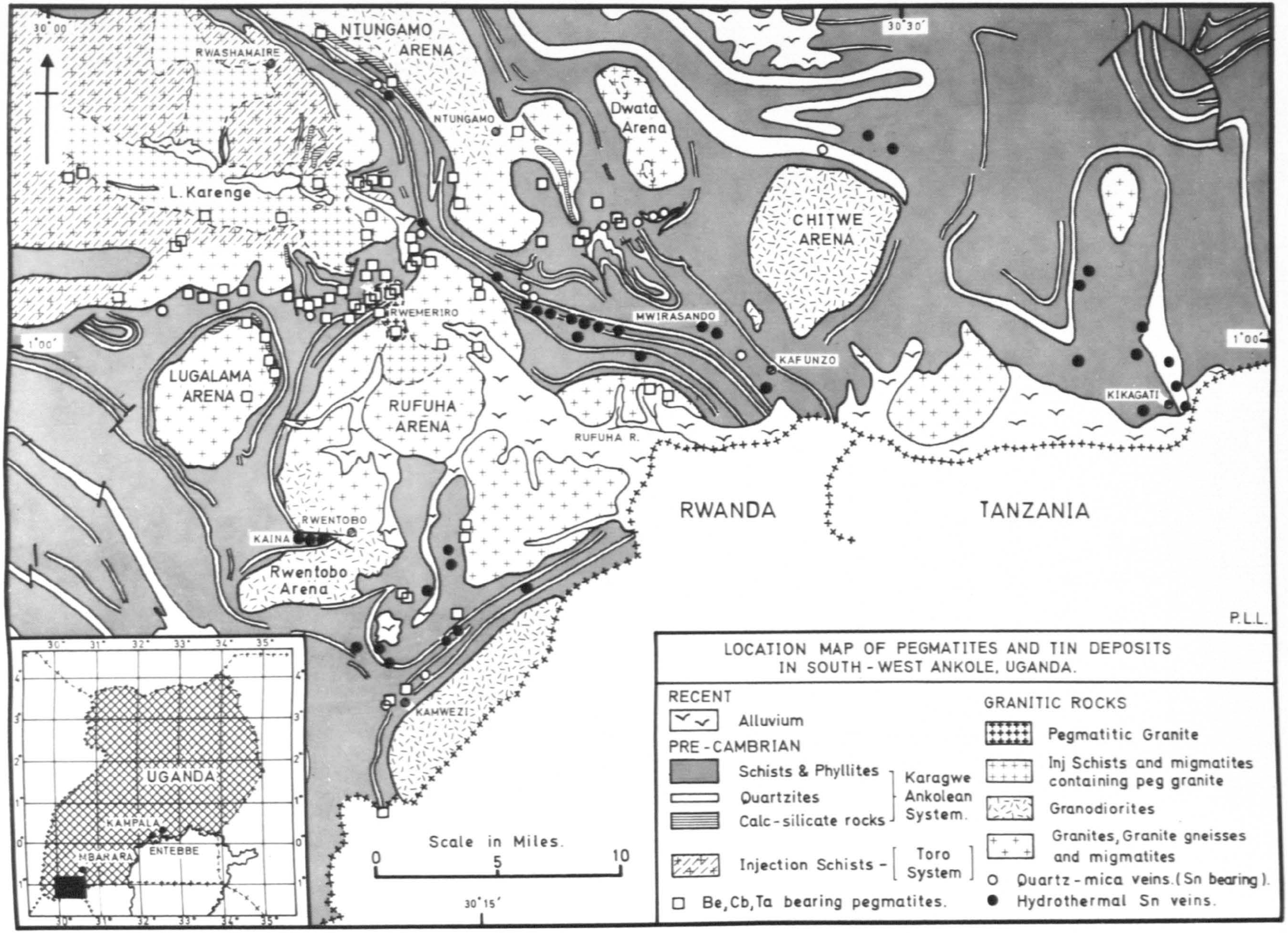
d. Lithian muscovite-albite and kaolinised lithian muscovite-albite replaced pegmatites. (Marginal pegmatites which occur either in marginal portions of the granitic rocks or in the adjacent K-A sediments).

3. Quartz-muscovite-kaolin pegmatites. (Exterior pegmatites which occur in K-A sediments at greater distances from granite than the the interior pegmatites).

4. Quartz-mica cassiterite-bearing veins ('Transitional' deposits which are intermediate in type to the pegmatites and the hydrothermal quartz-cassiterite bearing veins, are marginal, and occur in K-A sediments relatively close to the granitic rocks).

5. Hydrothermal quartz-cassiterite-bearing veins. (Exterior deposits which occur in K-A country rocks and are often situated furthest from the granites).

FIG 10


LOCATION MAP OF PEGMATITES AND TIN DEPOSITS
IN SOUTH - WEST ANKOLE, UGANDA.
RECENT
Alluvium
PRE - CAMBRIAN
Schists & Phyllites
Quartzites
Calc - silicate rocks
Karagwe Ankolean System.
Injection Schists - [Toro System]
Be, Cb, Ta bearing pegmatites.
GRANITIC ROCKS
Pegmatitic Granite
Inj Schists and migmatites containing peg granite
Granodiorites
Granites, Granite gneisses and migmatites
Quartz - mica veins. (Sn bearing).
Hydrothermal Sn veins.
Scale in Miles.
0
5
10
30°15'
30°00
30°30'
1°00'
NTUNGAMO ARENA
RWASHAMAIRE
NTUNGAMO
L. Karenge
Dwata Arena
CHITWE ARENA
RWEMERIRO
MWIRASANDO
KAFUNZO
KIKAGATI
LUGALAMA ARENA
RUFUHA ARENA
RUFUHA R.
RWENTOBO
KAINA
Rwentobo Arena
KAMWEZI
RWANDA
TANZANIA
UGANDA
KAMPALA
ENTEBBE
MBARARA
P.L.L.

The regional zoning of the mineral deposits of S.W. Ankole is similar to those described by workers in other parts of the world (see table 20). In S.W. Ankole the beryl-bearing pegmatites show a close association with major exposures of post-tectonic pegmatitic granite and only occur in close association with granitoid rocks that have been subjected to post-tectonic granitisation. The quartz mica veins and hydrothermal quartz veins all occur in K-A sediments which are situated at some distance from the nearest outcrops of granitoid rocks and in many cases occur where no evidence can be found for local formation of post-tectonic granite (see fig. 10).

A careful study of the distribution of the hydrothermal tin deposits has however shown that in some cases they occur in K-A rocks which lie in sharp contact with large masses of older (pre and syntectonic) granite. This is supported by evidence accumulated at Kaina tin mine, where hydrothermal tin deposits occur adjacent to a sheared and faulted contact between K-A schists and marginally altered (Rwentobo) 'granite'. Faulting and movement along the contact clearly post-dates formation and emplacement of the granite, and was accompanied by hydrothermal alteration of the marginal portions of the granite, and formation of the tin deposits in the adjacent K-A sediments.

It is believed that contacts between the granite and the K-A sediments acted as a channelway for hydrothermal solutions which migrated upwards from depth to form the hydrothermal quartz, and quartz-mica deposits.

Age relationships of the mineral deposits

Age determinations (carried out by Miss V.E. Kennedy 1966 at Oxford) on minerals collected by the writer from pegmatites and hydrothermal veins in S.W. Ankole (see table 21), indicate that these deposits are similar

Table 20.

Pegmatite fields which show a similar regional zonality to that found in S.W. Ankole

Region	Described by:	Year of Publication
AFRICA		
*Namaqualand	Gevers, T.W.	1936
African (several areas including Rwanda and the Eastern Congo)	Varlamoff, N.	1958
U.S.A.		
Maine	Hanley, J.B.	1939
U.S.S.R.		
Yablonsk ridge.	Tikhova, T.G.	1937
Karelia	Rytsk, Yu.E.	1959
Kola Peninsula	Mankievsky, S.I.	1962
Siberia	Dvorkin-Samarsky, V.A.	1962
U.S.S.R. (general)	Borovikov, P.P.	1961
U.S.S.R. (general)	Nedumov, I.B.	1962
*World (general)	Heinrich, E.W.	1953

Table compiled (with additions*) from Nedumov, I.B. (1964) pp. 119-123 'Regional zonality of pegmatite fields'.

TABLE 21.

AGE DETERMINATIONS ON MINERALS FROM PEGMATITES AND HYDROTHERMAL QUARTZ VEINS IN S.W. ANKOLE

Specimen No.	Sample	Locality		Age. Rb/sr.	K:Ar.
P 3	Microcline	Rwemeriro	(peg.)	690 m.y.	
P 4	Microcline	Nyabakweri	"	850 m.y.	
M 17	Muscovite	Rweibango	"	987 m.y.	
MOR	Lithian Muscovite	Rwemeriro	"	946 m.y.	494 m.y.
MOB	Biotite	Mungenyi	"	623 m.y.	
M 21	Muscovite	Mwirasando	(Sn vein)	827 m.y.	568 m.y.
M 23	Muscovite	Mwirasando	(Sn vein)	849 m.y.	

Unpublished Results Miss V.E. Kennedy 1966.

in age and may be closely related.

The apparent* ages range from 987 to 690 m.y. and clearly show that the mineral deposits are younger than the syntectonic granites formed in S.W. Uganda and elsewhere as a result of the Kibaran Orogeny (see table 21).

The micas MO and M17 are from granite pegmatites that occur directly associated with post-tectonic quartz-microcline-muscovite pegmatitic granite and give a minimum age of formation for the post-tectonic pegmatitic granites and the granite pegmatites of 987 m.y.

The apparent* ages of the micas from the cassiterite-bearing quartz veins are over 100 m.y. younger than those of the pegmatites and although the deposits are related it is possible that the tin mineralisation post-dates the formation of the pegmatites.

Mineralogical relationships of the mineral deposits

The mineral deposits of S.W. Ankole also appear to be related by several similarities in their mineralogy:

1. The country rocks adjacent to all the mineral deposit types have been tourmalinised and black tourmaline occurs in the deposits themselves. The mineral is always early in formation.

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*Footnote Not too much reliance can be placed on single mineral age determinations as these are very susceptible to 'younging'. This is well illustrated by the difference in age between the microcline (690 m.y.) and the lithian muscovite (946 m.y.) from the Rwemeriro pegmatite. Potassium-argon ages for two of the micas show that rejuvenation occurred as a result of an event approximately 500 m.y. ago (see also table 3). This event can be correlated with the Katangan Orogeny which affected portions of the Kibaran belt at circa 500 m.y.

2. Beryl has been found in the pegmatites, quartz-mica veins and hydrothermal quartz veins (although the bulk of this mineral is confined to the pegmatites).

3. Cassiterite occurs in all the deposit types (although major concentrations are confined to the hydrothermal quartz veins, and occasionally the quartz-mica veins). In the hydrothermal quartz- and quartz-mica veins the cassiterite occurs intimately associated with muscovite and in the pegmatites small quantities of cassiterite occur associated with albite, muscovite rock and lithian muscovite.

4. Muscovite, especially mica-rock, is common to all the mineral deposits.

5. Kaolin (representing altered feldspar) has been found in the pegmatites, quartz-mica veins and occasionally in the hydrothermal quartz veins.

6. Quartz is ubiquitous and forms substantial portions of all the deposits.

Conclusions

The beryl-bearing granite pegmatites, the quartz mica-cassiterite-bearing veins and the hydrothermal quartz cassiterite-bearing veins of S.W. Ankole are all related and are believed to have been formed as a result of two different but related processes which operated during the final stages of the Kibaran orogeny.

The pegmatites were probably formed from magma derived by potash metasomatism and palingenesis of pre-existing granitic rocks at scattered centres of dynamothermal activity (i.e. 'hot spots' in the Ankole anticlinorium), whereas the quartz mica and the hydrothermal quartz cassiterite-bearing veins were formed from hydrothermal fluids derived by similar processes operating on a large scale at depth.

The pegmatites, quartz mica and hydrothermal quartz veins are believed to have a common origin - they were either directly or indirectly derived from the granitic rocks - and they were formed as a result of magmatic and hydrothermal processes which operated during the closing stages of the Kibaran orogeny.

SECTION II

THE GEOCHEMISTRY OF THE TIN AND BERYLLIUM MINERALISATION

CHAPTER V

GENERAL GEOCHEMISTRY OF THE TIN AND BERYLLIUM MINERALISATION IN S.W. ANKOLE

The Geochemistry of the Tin and Beryllium Mineralisation in S.W. Ankole Uganda

Introduction

In S.W. Ankole there has been widespread tin and beryllium mineralisation which is represented by the occurrence of three main deposit types:

1. Beryl-bearing granite pegmatites
2. Quartz-mica cassiterite-bearing veins
3. Hydrothermal quartz cassiterite-bearing veins

All have been found to contain some beryl or cassiterite although in widely differing proportions. The granite pegmatites often contain economic accumulations of beryl and only traces of cassiterite, whereas the quartz-mica and the hydrothermal quartz veins contain very high concentrations of cassiterite relative to beryl.

In all cases some geochemical concentration of the elements tin and beryllium has occurred and results obtained by the G.S.G.B. - A.E.D. (1959-61) and others (see table 22), show that in addition to tin and beryllium minerals, the pegmatites and hydrothermal veins contain considerable amounts of trace tin and beryllium dispersed through the major (and minor) minerals. The quartz-mica veins which show similarities to both quartz-mica-kaolin pegmatites and the hydrothermal quartz veins contain a considerable amount of trace tin dispersed in the micas (200-550 ppm. Sn and up to 25 ppm Be).

The presence of tin and beryllium (although in widely differing proportions) in the three deposit types is interesting and indicates that they are probably geochemically related.

Table 22. *To show the Mode of Occurrence of Tin and Beryllium in the Granite Pegmatites and Hydrothermal quartz cassiterite bearing veins of S. W. Ankole

BERYLLIUM		TIN	
1. Beryllium Minerals		1. Tin Minerals	
Granite pegmatites	Hydrothermal veins	Granite pegmatites	Hydrothermal veins
BERYL $Al_2Be_3(Si_6O_{18})$ Often present in economic concentrations (i.e.: 1-3% of pegmatite) BeO content (assay) = 11.4 - 13.5%	BERYL Only present in small quantities. (0.04-0.05% BeO (as beryl) has been found in mine tailings at Mwirasando Tin Mine.) BeO content (assay) = 11.5 - 12.2%	CASSITERITE SnO_2 Traces of cassiterite only Approximate Sn content = 70 - 75%	CASSITERITE Often present in economic concentrations Approximate Sn content = 75%
CHRYSOBERYL $BeAl_2O_4$ Traces only BeO content = 16.8 - 18.8%	Chrysoberyl not found		
Euclase not found	EUCLASE $BeAlSiO_4(OH)$ Traces only Approximate BeO content = 17%		
BERTRANDITE $Be_4Si_2O_7(OH)_2$ Traces (very rare) Approximate BeO content = 42%	Bertrandite not found		
PHENAKITE Be_2SiO_4 Traces Approximate BeO content = 44%	Phenakite not found		
Beryllian Margarite not found	BERYLLIAN MARGARITE $CaAl_2(Si,Al,Be)_4O_{10}(OH)_2$ Traces (very rare) BeO content = 2.5%		

Table 22. Cont'd.

BERYLLIUM		TIN	
2. Beryllium bearing minerals		2. Tin bearing minerals	
Granite pegmatites ALTERATION PRODUCTS of Montebrasite (amblygonite) Beryllium bearing secondary phosphates of the Goyazite and Variscite series. BeO content :: up to 0.2%	Hydrothermal veins No secondary phosphates	Granite pegmatites COLUMBITES/TANTALITES $(Fe, Mn) (Nb, Ta)_2O_6$ contain 0.10 - 1.00% SnO_2	Hydrothermal veins No Nb/Ta Minerals ↓
		TIN TANTALITE (Nyanga 2) contains up to 11.17% SnO_2	↓
		TAPIOLITE $Fe Ta_2O_6$ (Nyanga) contains 1.13% SnO_2	↓
		MANGANOCOLUMBITE (Kazumo) contains 0.3% SnO_2 From: O. von Knorring 1964-'65,'66,'67 and '68.	↓

Table 22. Cont'd.

BERYLLIUM		TIN	
3. Major minerals containing traces of Beryllium		3. Major minerals containing traces of Tin	
Granite pegmatites	Hydrothermal veins	Granite pegmatites	Hydrothermal veins
MUSCOVITE 0.003 - 0.009% BeO 11 - 32 ppm. Be	MUSCOVITE 0.006 - 0.007% BeO 22 - 25 ppm. Be	MUSCOVITE 20 - 500 ppm. Sn	MUSCOVITE 250 - 600 ppm. Sn Anal: P.L.L.
KAOLIN/SERICITE 0.002 - 0.005% BeO 7 - 22 ppm. Be	KAOLIN/SERICITE BeO Be contents similar	LITHIAN MUSCOVITES 125 - 500 ppm. Sn Anal: P.L.L.	No lithian muscovite
SODIUM FELDSPAR (ALBITE) 0.002 - 0.007% BeO 7 - 22 ppm. Be	No unaltered albite		
POTASSIC FELDSPARS (Microcline & perthite) 0.001 - 0.004% BeO 4 - 14 ppm. Be	No unaltered K feldspar		
QUARTZ (Adjacent to beryl) up to 0.003% BeO 11 ppm. Be	QUARTZ (Adjacent to beryl) up to 0.002% BeO 7 ppm. Be		

Table 22. Cont'd.

BERYLLIUM		TIN	
4. Minor and accessory minerals containing traces of beryllium		4. Minor and accessory minerals containing traces of tin	
Granite pegmatites	Hydrothermal veins	Granite pegmatites	Hydrothermal veins
AMBLYGONITE 0.001% BeO 4.0 ppm. Be	No Amblygonite	BIOTITE (Mungenyi) 80 ppm. Sn Anal: P.L.L.	No Biotite
ALTERED SPODUMENE LATHS 0.001 - 0.003% BeO 4 - 11 ppm. Be	No Spodumene	TOURMALINE (VERDELITE) from Mutaka 50 ppm. Sn Anal: P.L.L.	No Verdelite
MANGANESE MINERALS 0.001 - 0.002% BeO 4 - 7 ppm. Be	No Data		
TOURMALINE 0.002% BeO 7 ppm. Be	No Data		

* Data (except where indicated otherwise) taken from Unpublished Mineralogical Reports of the Geological Survey of Great Britain - Atomic Energy Division, (1965-61), and from Gallagher, M.J. & Hawkes, J.R. (1966).

G.S.G.B. - A.E.D. unpublished information made available by courtesy of Mr.S.H.U. Bowie (Chief Geologist)

In order to explain the concentration of tin and beryllium in the different deposit types it was decided to make a study of the geochemistry of these elements in the granites, mineral deposits and their country rocks. The investigation was carried out with a view to finding the source of the tin (and beryllium) and to discover the mechanisms which led up to the concentration of these elements to form ore.

The Distribution of Tin and Beryllium in the Granitic and Sedimentary rocks of S.W. Ankole

Previous work

Previous work by the Geological Survey of Great Britain - Atomic Energy Division (1959-61) see table 23 , has shown that the average beryllium content of a small number of granitic and meta-sedimentary rocks from S.W. Ankole, are fairly close to those quoted for average granites and clays/shales in the earth's crust (Re: U.S.G.S. Prof. Paper 440 - D. 1967).

The ranges of concentrations quoted indicate the presence of relatively high concentrations (up to 16 ppm.) of beryllium in some of the granites and fairly high concentrations (up to 22 ppm) of beryllium in some of the meta-sediments.

No previous work has been carried out on the distribution of tin in the rocks.

In 1966 it was decided to carry out a detailed study of the distribution of both tin and beryllium in the rocks of S.W. Ankole, and to try to establish the source of these two elements, and extensive geochemical sampling of all the main rock types was carried out.

Method

283 samples were collected in the field, and included 145 samples of granitoid rocks and 124 samples of K-A sediments. Great care was taken to obtain unweathered and representative material in each case, and the methods of sampling are described in appendix III .

237 of the samples were spectrographically analysed for tin and beryllium by the Uganda Geological Survey and the results are presented in tables 43 . A further 46 samples were analysed colorimetrically for tin only and the

Table 23. Tin and Beryllium contents of the rocks of S.W. Ankole
(*Data available prior to 1965)

		Range % BeO	= ppm. Be	Average % BeO	= ppm. Be	+Average Earth's Crust
1. Non pegmatite beryllium in rocks of S.W. Uganda						
a. Granitic rocks	32 specimens	0.0 - 0.0045	0 - 16	0.0011	3.9	5.5
b. Metasedimentary rocks	22 specimens	0.0 - 0.0060	0 - 22	0.0017	6.1	3.0
c. Calc-silicate rocks	1 specimen	0.001	4	-	-	
2. Non pegmatite beryllium in pegmatite wall rocks				Average % BeO	= ppm. Be	
a. Granitic wall rocks	46 specimens (including 11 from the Kazumo pegmatite)			0.0015	5.4	
b. Metasedimentary rocks	32 specimens (including 24 from pegmatites)			0.0019	6.8	
3. Beryllium in beryl-free pegmatite		Range % BeO	= ppm. Be			
		0.002 - 0.005	7 - 18			

* Data compiled from Unpublished Mineralogical Reports of the Geological Survey of Great Britain - Atomic Energy Division (1959-61).
G.S.G.B. - A.E.D. unpublished information made available by courtesy of Mr. S.H.U. Bowie (Chief Geologist).

\+ U.S.G.S. Prof. Paper 440-D, 1967.

BeO determinations by -neutron analysis.

results also appear in table 43 . (Colorimetric redeterminations of tin were also carried out on 26 samples selected from those analysed by the U.G.S.)

For evaluation of the results the samples were divided into 5 main groups:-

1. Unaltered foliated granites, granodiorites, gneisses and migmatites.
2. Hydrothermally altered marginal granitoid rocks and altered granitic wall rocks.
3. Post-tectonic pegmatitic granites.
4. Unaltered Karagwe-Ankolean sedimentary rocks.
5. Altered Karagwe-Ankolean contact and wall rocks.

The results from each group were plotted on histograms for comparison.

Results for beryllium

The histograms obtained for beryllium are presented in figs.11-13 .

1. The unaltered foliated granites, granodiorites, gneisses and migmatites (which have not been subjected to post-tectonic mineralisation) only contain very small quantities of beryllium (range 0-15 ppm) and the histogram shows that 94% of the samples contain <5 ppm. of Be and 99% of the samples contain <10 ppm. The mean beryllium content 2.3 ppm. for the granitoid rocks is below the average value for granites and granodiorites in the earth's crust (5.5 ppm. Ref. Data of Geochemistry Chap. D. p. D 13. U.S.G.S. Prof. Paper 440 - D. 1967).

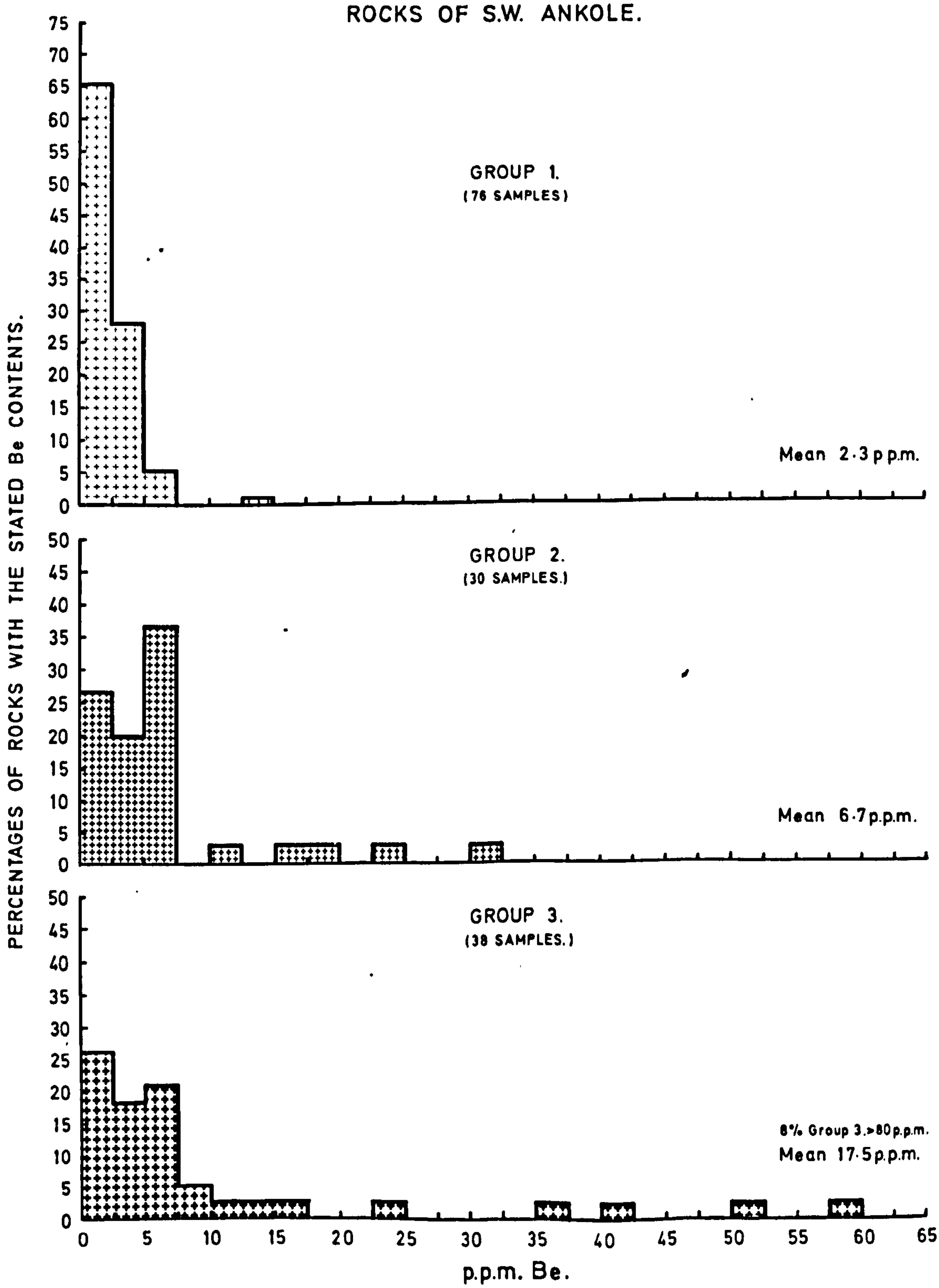
2. The altered marginal granitoid rocks (which occur at the margins of the arena granites) and the altered granitic contact rocks (which occur adjacent to mineral deposits) also contain above average amounts of beryllium (range 0-35 ppm.). 53% of these rocks contain >5 ppm. of Be and 17% contain >10 ppm. Be.

Key to the histograms showing the distribution of tin and beryllium in the rocks of S.W. Ankole

Group 1.	Unaltered foliated granites, granodiorites, gneisses and migmatites.
Group 2.	Hydrothermally altered marginal granitoid rocks and altered granitic wall rocks.
Group 3.	Post-tectonic pegmatitic granites.
Group 4.	Unaltered Karagwe-Ankolean sedimentary rocks.
Group 5.	Altered Karagwe-Ankolean contact and wall rocks.

FIG 11

DISTRIBUTION OF Be IN THE GRANITOID ROCKS OF S.W. ANKOLE.



3. The post-tectonic pegmatitic granites (which have formed as a result of post-tectonic potash-metasomatism and palingenesis of earlier granitic rock types) contain above average amounts of beryllium (range 0-135 ppm). The histogram shows that 55% contain > 5 ppm of Be and 29% contain > 10 ppm.

4. Samples of K-A country rock taken from areas unaffected by hydrothermal alteration and mineralisation all contain less than 5 ppm. beryllium (fig. 12).

5. Hydrothermally altered and tourmalinised K-A contact and wall rocks have been found to contain above average amounts of beryllium (range 0-20 ppm). The average beryllium content has been found to be 5.9 ppm which is above that quoted in U.S.G.S. pp. 440-D for clays and shales - 3.0 ppm. 61% of the samples (see histogram) contain > 5 ppm Be and 8% contain more than 10 ppm.

The granitoid rocks in Group 1 were further subdivided to determine whether there are any differences in beryllium content in the different rock types within the group. Histograms were plotted for:-

1a. Granodiorites and prophyroblastic microcline-biotite granites

1b. Aplites (fig 13).

Only in the case of aplites has there been any notable increase in the percentage of samples containing more than 5 or 10 ppm Be. 38% of the aplites contain > 5 ppm. of Be and 13% contain more than 10 ppm. Be. A summary of the results for Be is presented in table 24 .

<u>Conclusions</u>

With the exception of some varieties of post-tectonic pegmatitic granites (in which the beryllium content may rise to over 135 ppm), and the hydrothermally altered marginal or contact granitoid rocks (in which the beryllium content may exceed 40 ppm) - the granitoid rocks of S.W. Ankole

FIG 12

DISTRIBUTION OF Be IN THE SEDIMENTARY ROCKS OF S.W. ANKOLE.

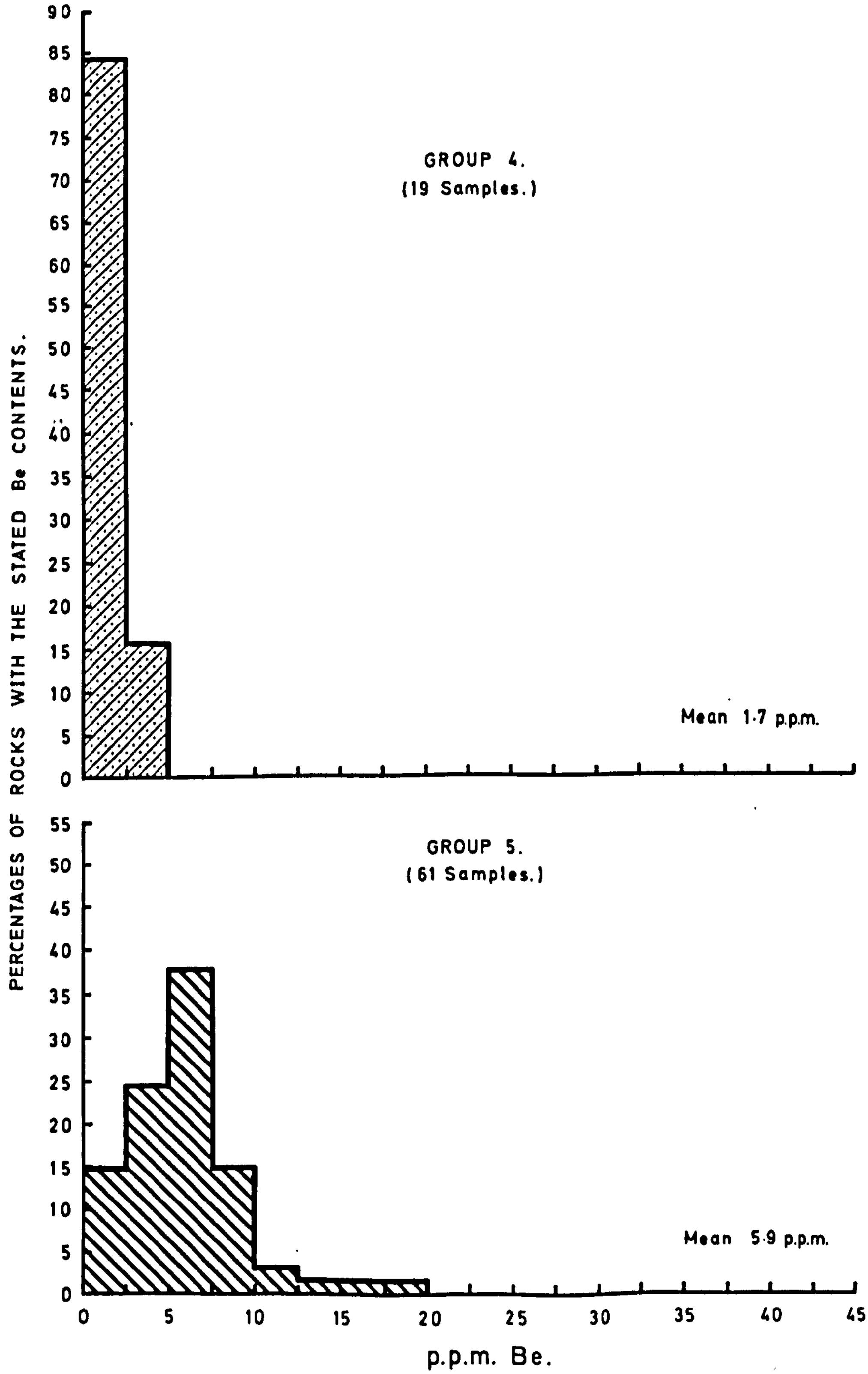


FIG 13

DISTRIBUTION OF Be IN GRANODIORITES AND APLITES.

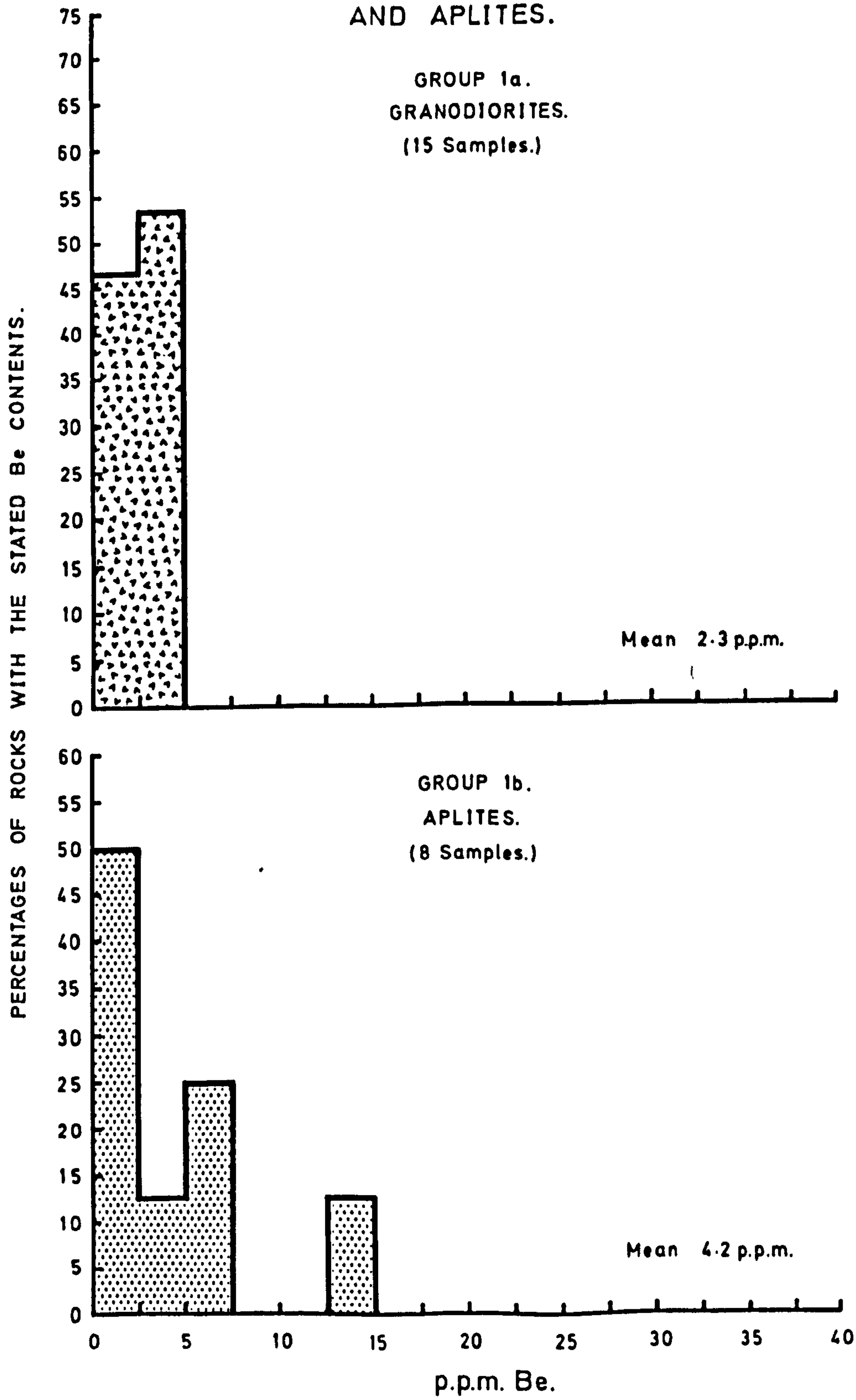


TABLE 24. SUMMARY OF GEOCHEMICAL RESULTS FOR BERYLLIUM IN THE ROCKS OF S.W. ANKOLE

GROUP	NO. OF SAMPLES	ARITHMETIC MEAN Be CONTENT PPM.	ARITHMETIC MEAN Be CONTENT PPM. (EXCLUDING ERRATIC HIGH VALUES)	NO. OF SAMPLES
1	77	2.3	-	-
2	30	6.7	-	-
3	38	17.5	10.0	35
4	19	1.7	-	-
5	61	5.9	-	-
SUBGROUPS				
1A	15	2.3	-	-
1B	8	4.2	-	-

contain ~~normal~~ average amounts of beryllium for granitic rocks in the earth's crust. The post-tectonic pegmatitic granites which were formed late in the Kibaran Orogeny have been found to contain a higher average concentration of beryllium (17.5 ppm) than the earlier (synorogenic) granitic rocks (2.3 ppm.) and this is in agreement with observations made by C.G.B. Du Bois (1962) in Kenya, where the late orogenic granitic rocks have also been found to contain the highest concentrations of beryllium. The unaltered rocks of the K-A system contain normal amounts of beryllium (for clays and shales), but where they have been hydrothermally altered, tourmalinised or occur adjacent to mineral deposits their beryllium content may rise to over 35 ppm.

Results of Tin

The histograms obtained for tin in the various rock groups are presented in figs. 14-16 .

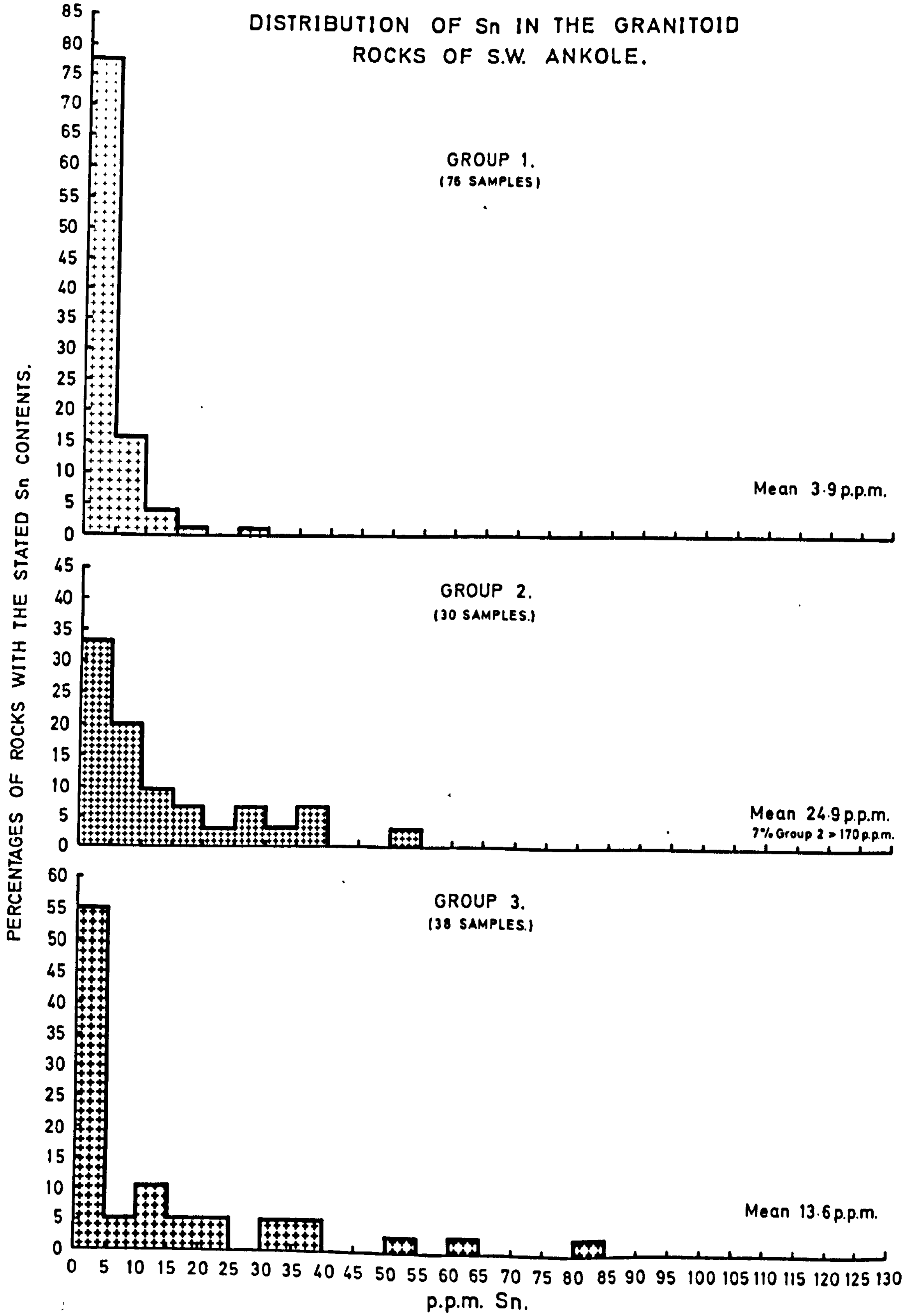
1. The unaltered foliated granites, granodiorites, gneisses and migmatites only contain small quantities of tin, (range 0-30 ppm) and histogram. 1 shows that 78% of the samples contain <5 ppm of Sn and 93% contain <10 ppm. The average tin content for the unaltered granitoid rocks in 3.9 ppm which lies veryclose to the average for felsic granites and granodiorites in the earths crust (3.0 ppm. Ref. U.S.G.S. P.P. 440-D).

2. The altered marginal granitoid rocks and the altered granitic contact rocks ~~also~~ contain above average amounts of tin (range 0-213 ppm). 67% of these rocks contain >5 ppm Sn and 47% contain >10 ppm.

3. The pegmatitic granites contain above average amounts of tin (range 0-80 ppm. and the histogram shows that 45% of the pegmatitic granites contain >5 ppm Sn and 39% contain >10 ppm of tin.

4. Samples of K-A country rock from areas unaffected by hydrothermal alteration, tourmalinisation or mineralisation all contain less than

FIG 14



DISTRIBUTION OF Sn IN THE GRANITOID ROCKS OF S.W. ANKOLE.
GROUP 1.
(76 SAMPLES)
Mean 3·9 p.p.m.
GROUP 2.
(30 SAMPLES.)
Mean 24·9 p.p.m.
7% Group 2 > 170 p.p.m.
GROUP 3.
(38 SAMPLES.)
Mean 13·6 p.p.m.
PERCENTAGES OF ROCKS WITH THE STATED Sn CONTENTS.
p.p.m. Sn.

10 ppm of tin. The average tin content of the unaltered K-A sediments (2.9 ppm) lies below that for clays and shales - 6-10 ppm (Re. U.S.G.S. pp. 440-D).

5. A large proportion of the hydrothermally altered and tourmalinised K-A country rocks (particularly those occuring adjacent to tin deposits) contain large amounts of tin (up to 240 ppm) and 77% of the group contain > 10 ppm of tin.

In order to study the distribution of tin in these rocks more clearly, the hydrothermally altered rocks were divided into three sub-groups.

5a. Hydrothermally altered (tourmalinised and sericitised) K-A country rocks found remote from granite or mineral deposits (fig.16/1). Although these rocks are not intimately associated with any mineral deposits hydrothermal alteration has resulted in a small increase in tin content (range 0-30 ppm). 24% of the rocks (see histogram) contain > 10 ppm of Sn.

5b. Hydrothermally altered K-A country rocks from adjacent to granite, pegmatites and quartz veins (excluding cassiterite bearing veins). Although not indirectly affected by tin mineralisation these rocks have been subjected to introduction of tin from other deposit types. The rocks have been found to contain 0-180 ppm Sn and 76% of the group contain > 10 ppm Sn.

5c. Hydrothermally altered K-A country rocks from adjacent to cassiterite-bearing quartz-mica and hydrothermal quartz veins. The rocks of this group are all intimately associated with tin deposits and contain a wide range of tin concentrations 0-240 ppm. 100% of the samples contain > 10 ppm Sn and over 66% lie in the range 10-110 ppm Sn.

The highest values 110-240 ppm were obtained from samples taken from immediately adjacent or very close to hydrothermal tin veins.

FIG 15

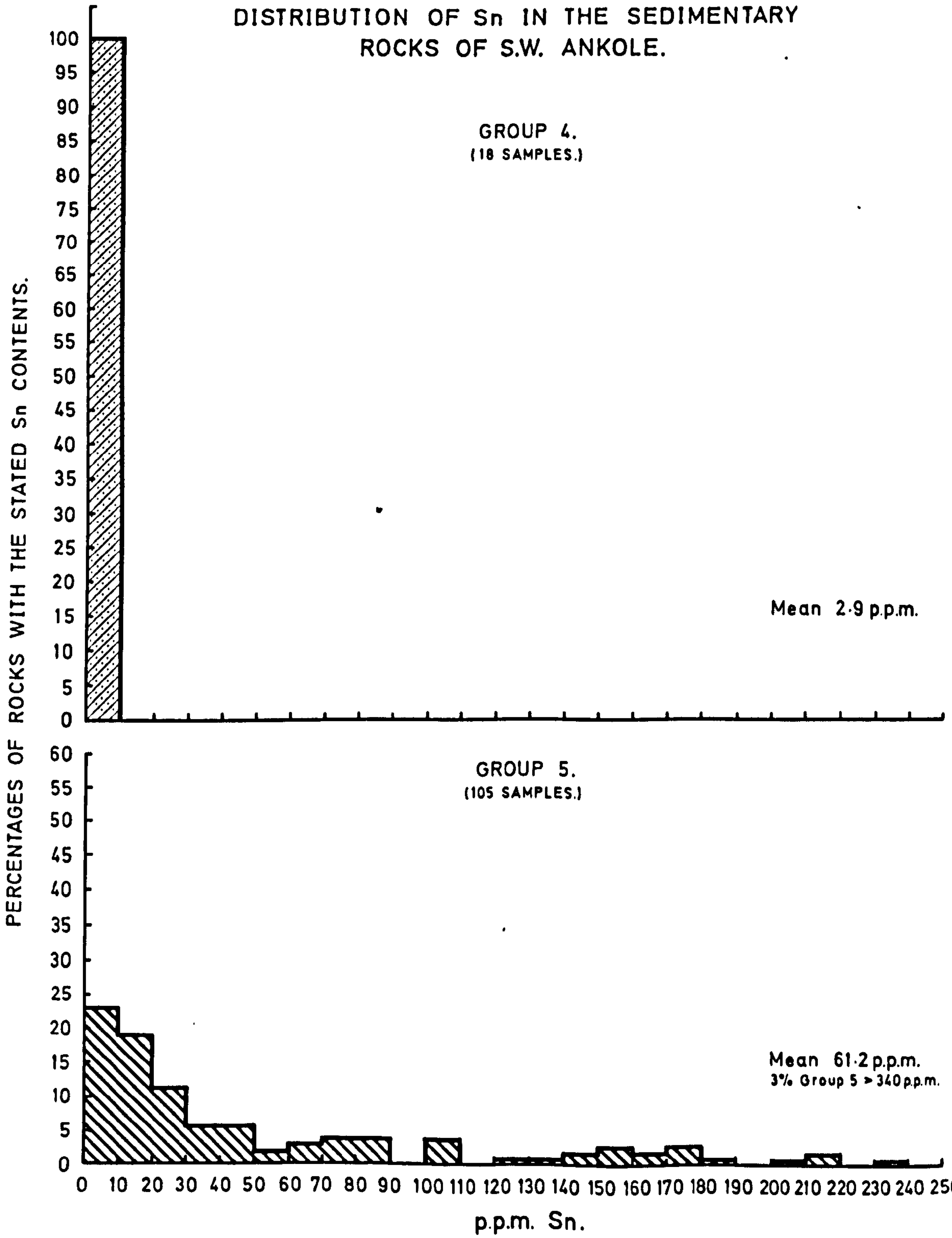
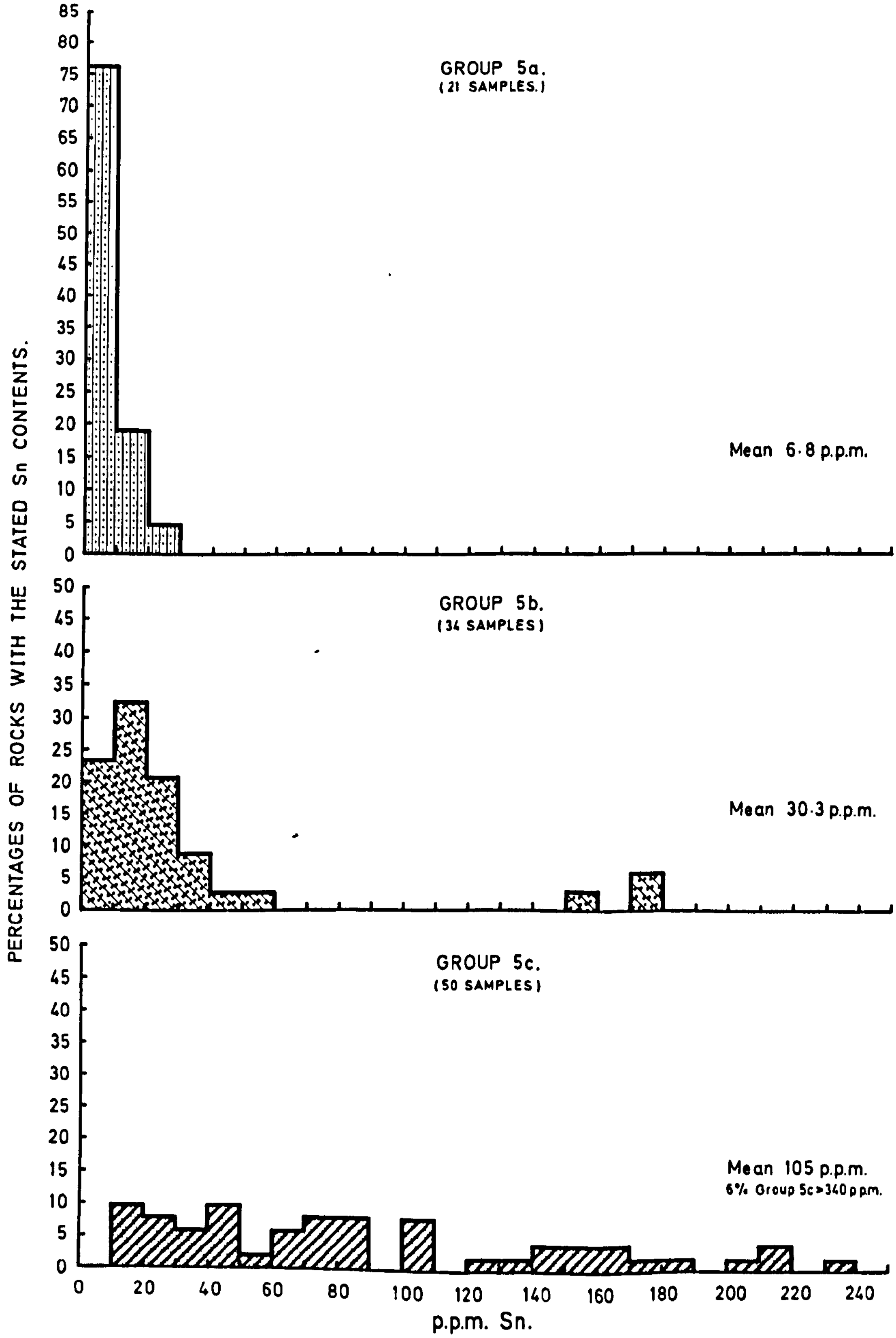

DISTRIBUTION OF Sn IN THE SEDIMENTARY ROCKS OF S.W. ANKOLE.
GROUP 4.
(18 SAMPLES.)
Mean 2·9 p.p.m.
GROUP 5.
(105 SAMPLES.)
Mean 61·2 p.p.m.
3% Group 5 > 340 p.p.m.
PERCENTAGES OF ROCKS WITH THE STATED Sn CONTENTS.
p.p.m. Sn.
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250

FIG 16

DISTRIBUTION OF Sn IN HYDROTHERMALLY ALTERED K-A COUNTRY ROCKS.



The granitoid rocks of group 1 were further subdivided to determine whether there are any differences in tin content between the rock types which make up the group. The subdivisions used were the same as for beryllium (see p. 104). Histograms were plotted for each subgroup (fig. 17) but only the granodiorites and prophyroblastic microcline biotite granites were found to differ from group 1 as a whole. 15% of these rocks were found to contain 10 ppm of tin (in contrast to 6% for group 1). (A summary of the results for Sn appear in table 25). The samples which contain > 10 ppm of tin come from the Chitwe Arena, the Ibanda Arena and from Kasanyi in the Sina arena - Karagwe Tinfields, N.W. Tanzania. It would appear from the small number of analyses available that the 'granites' at Chitwe, Ibanda and Kasanyi contain more tin than those found in the Rwentobo, Ntungamo and Kamwezi arenas. The Kasanyi granite from N.W. Tanzania is very different from those at Ibanda and Chitwe and the sample collected (which contains 17 ppm Sn), consists of fairly coarse-grained weaky porphyroblastic muscovite-biotite granite in which the predominant mica is muscovite which has a pale brownish colour. The granite has been metasomatically altered and contains substantial amounts of late formed albite and some tourmaline.

Conclusions

With the exception of some varieties of post-tectonic pegmatitic granite (in which the tin content may reach 80 ppm) and the hydrothermally altered marginal granitoid rocks and granite wall rocks (in which the tin content may reach 45 ppm) the granitoid rocks contain average amounts of tin for granitic rocks in the earth's crust. The Chitwe, Ibanda and Kasanyi 'granites' are exceptional in that they are the only 'arena granites' found to contain above average concentrations of tin (10-30 ppm). The possible significance of

FIG 17

DISTRIBUTION OF Sn IN APLITES AND GRANODIORITES.

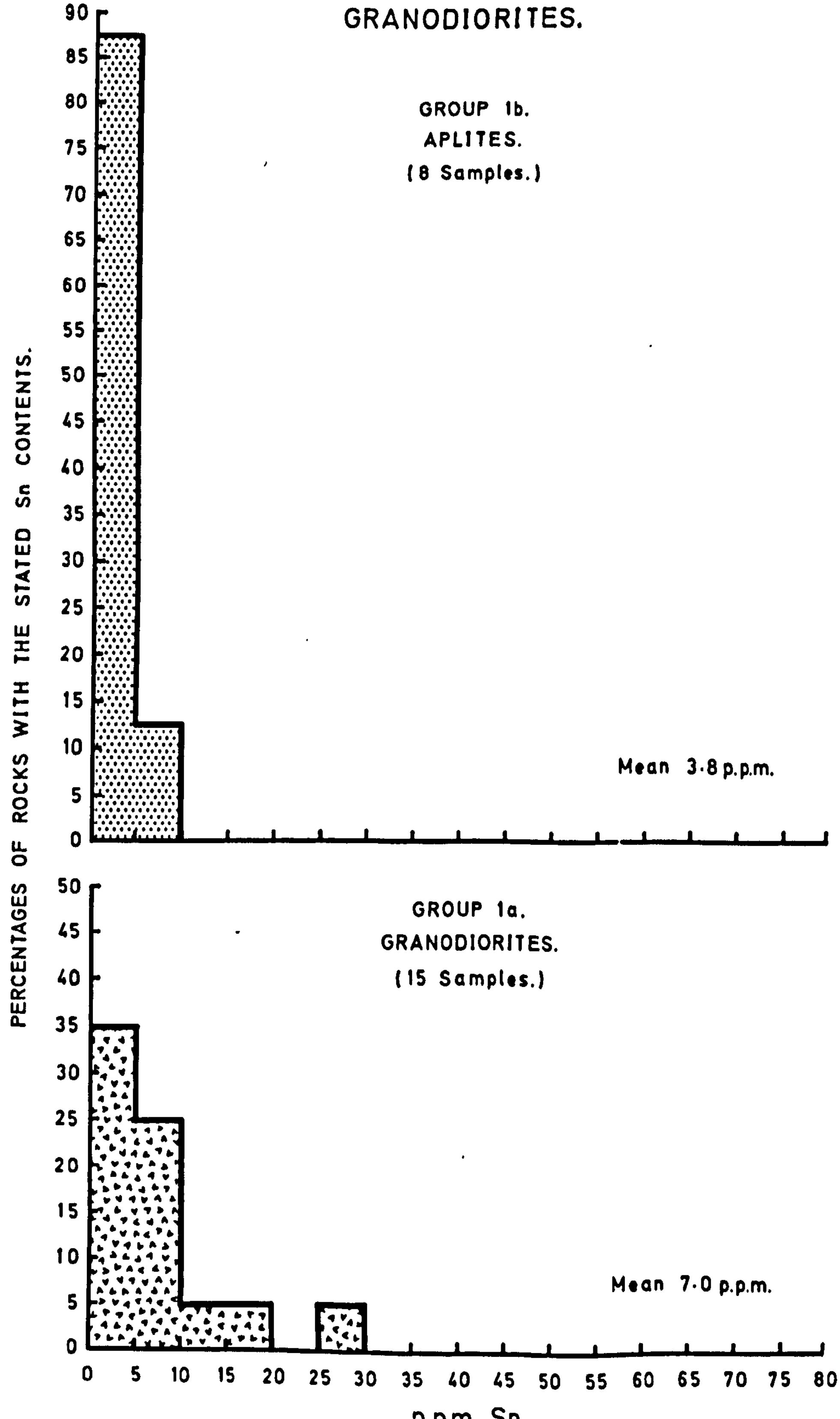


TABLE 25. SUMMARY OF GEOCHEMICAL RESULTS FOR TIN IN THE ROCKS OF S.W. ANKOLE

GROUP	NO. OF SAMPLES	ARITHMETIC MEAN Sn CONTENT PPM.	ARITHMETIC MEAN Sn CONTENT PPM. (EXCLUDING HIGH ERRATIC VALUES)	NO. OF SAMPLES
1	77	3.9	-	-
2	30	24.9	12.8	28
3	38	13.6	-	-
4	18	2.9	-	-
5	105	61.2	52.2	102
SUBGROUPS				
5a	21	6.8	-	-
5b	34	30.3	17.1	31
5c	50	105.0	88.3	47

this will be discussed later (see p. 119).

Unaltered rocks of the K-A system contain below average amounts of tin (for clays and shales) and only those affected by hydrothermal alteration associated with post-tectonic mineralisation contain above average tin concentrations.

The evidence so far for tin and beryllium indicates that both elements have been concentrated as a result of magmatic, metasomatic, and hydrothermal processes which operated at a late stage in the Kibaran orogeny. With certain exceptions only rocks that have suffered post-tectonic palingenesis or have been hydrothermally or metasomatically altered have been found to contain above-average concentrations of tin and beryllium

B.

Evidence for epigenetic origin of the mineral deposits

Some of the highest concentrations of tin and beryllium have been found in wall rocks of the mineral deposits and there can be no doubt that the tin and beryllium have been epigenetically introduced during formation of the mineral deposits. In order to test this theory it was decided to analyse samples collected at intervals from adjacent to several mineral deposits to determine whether epigenetic dispersion patterns have been produced. The results appear in figs. 18-22. Epigenetic dispersion patterns have been found to occur in nearly all cases with a sharp increase in concentration of tin and beryllium in the country rocks as the mineral deposits are approached. One apparent exception has been found to occur at Mwirasando (see fig. 22), where erratic high values of tin and beryllium have been obtained even at considerable distances from the main veins. The reason for this is that alteration of the country rocks has not been confined to the immediate vicinity of the main veins and the intervening rocks have also been strongly affected. The high values do not reflect an original

FIG 18

EPIGENETIC DISPERSION PATTERNS FOR Sn AND Be ADJACENT TO HYDROTHERMAL QUARTZ VEINS AT BURAMA RIDGE.

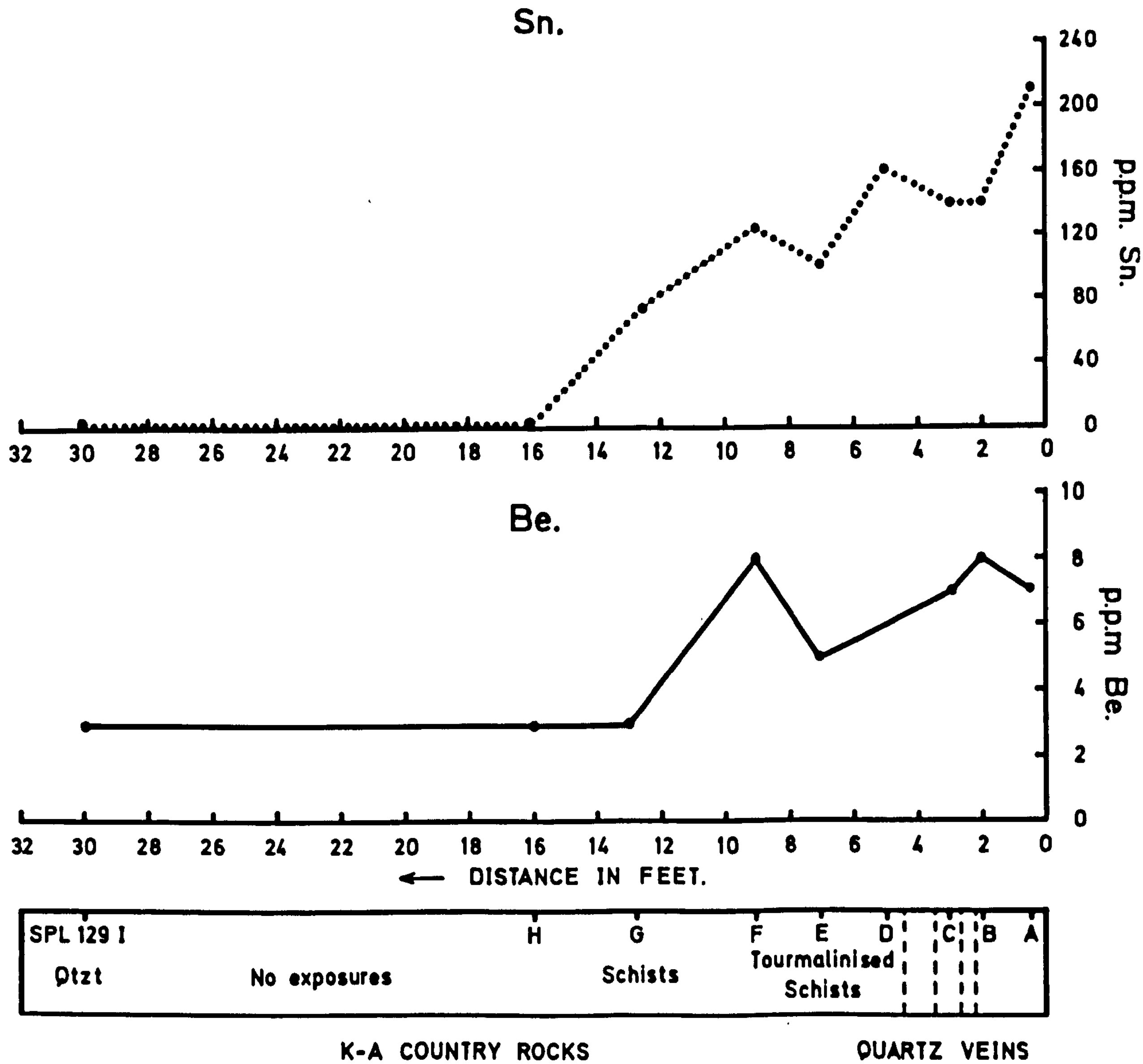
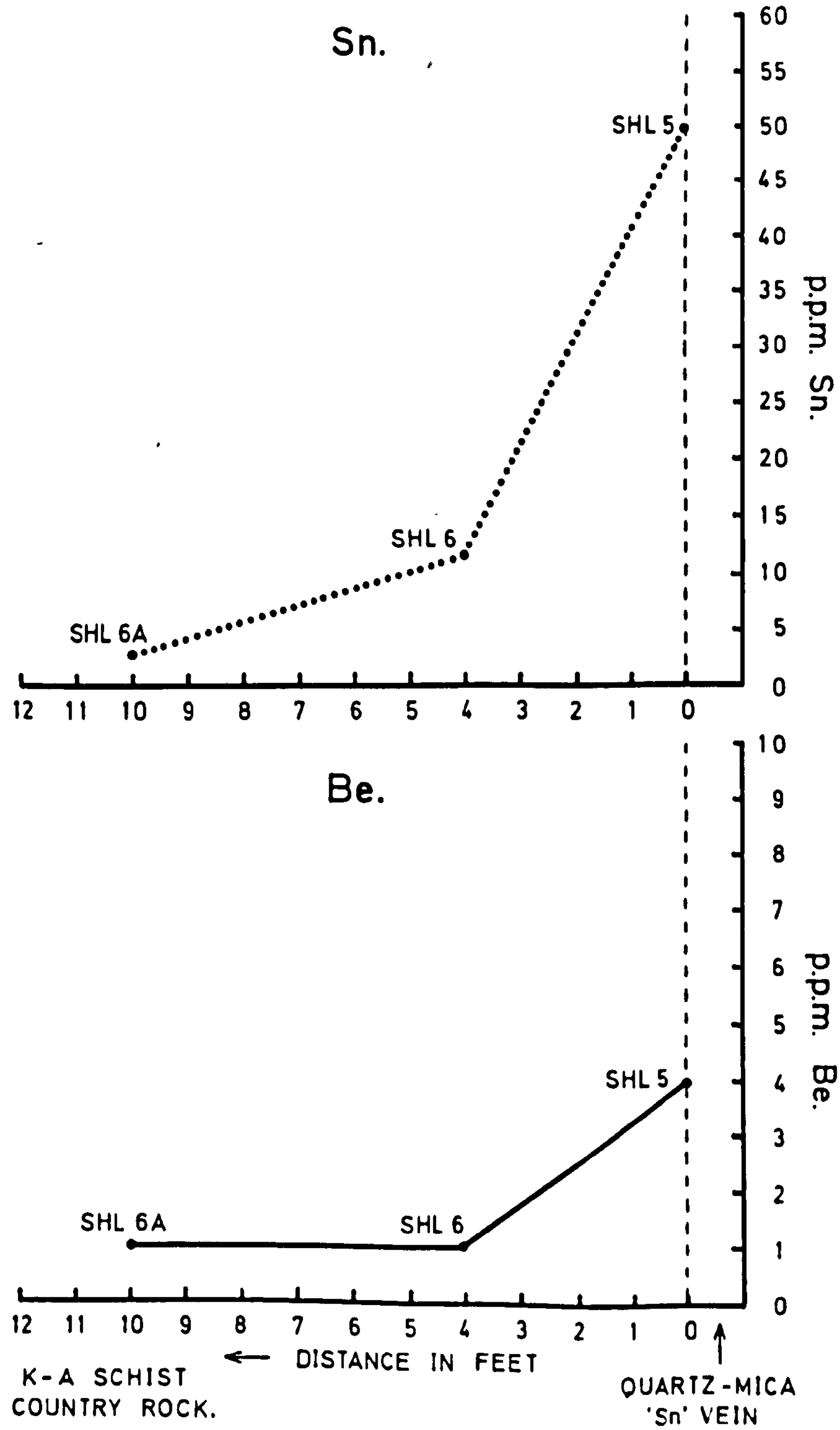


FIG 19

EPIGENETIC DISPERSION PATTERNS FOR Sn AND Be ADJACENT TO A QUARTZ-MICA 'Sn' VEIN AT KAKANYORO, BURAMA-RIDGE.



EPIGENETIC DISPERSION PATTERNS FOR Sn AND Be ADJACENT TO A QUARTZ DYKE AND MICA STRINGERS AT KAINA.

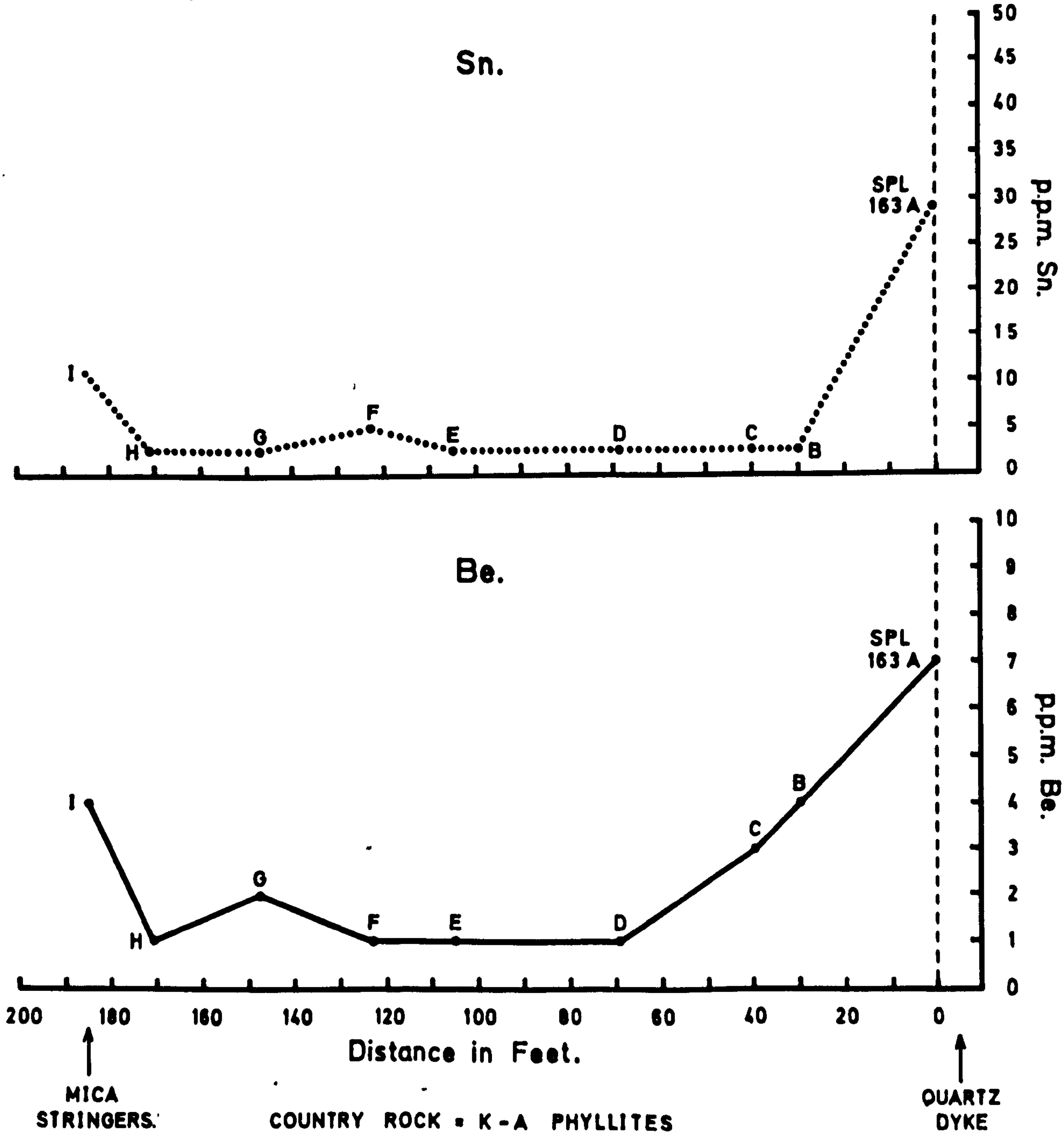


FIG 20

FIG 21

EPIGENETIC DISPERSION PATTERNS FOR Sn AND Be ADJACENT TO A QUARTZ-GREISEN VEIN AT KYAMUGASHE.

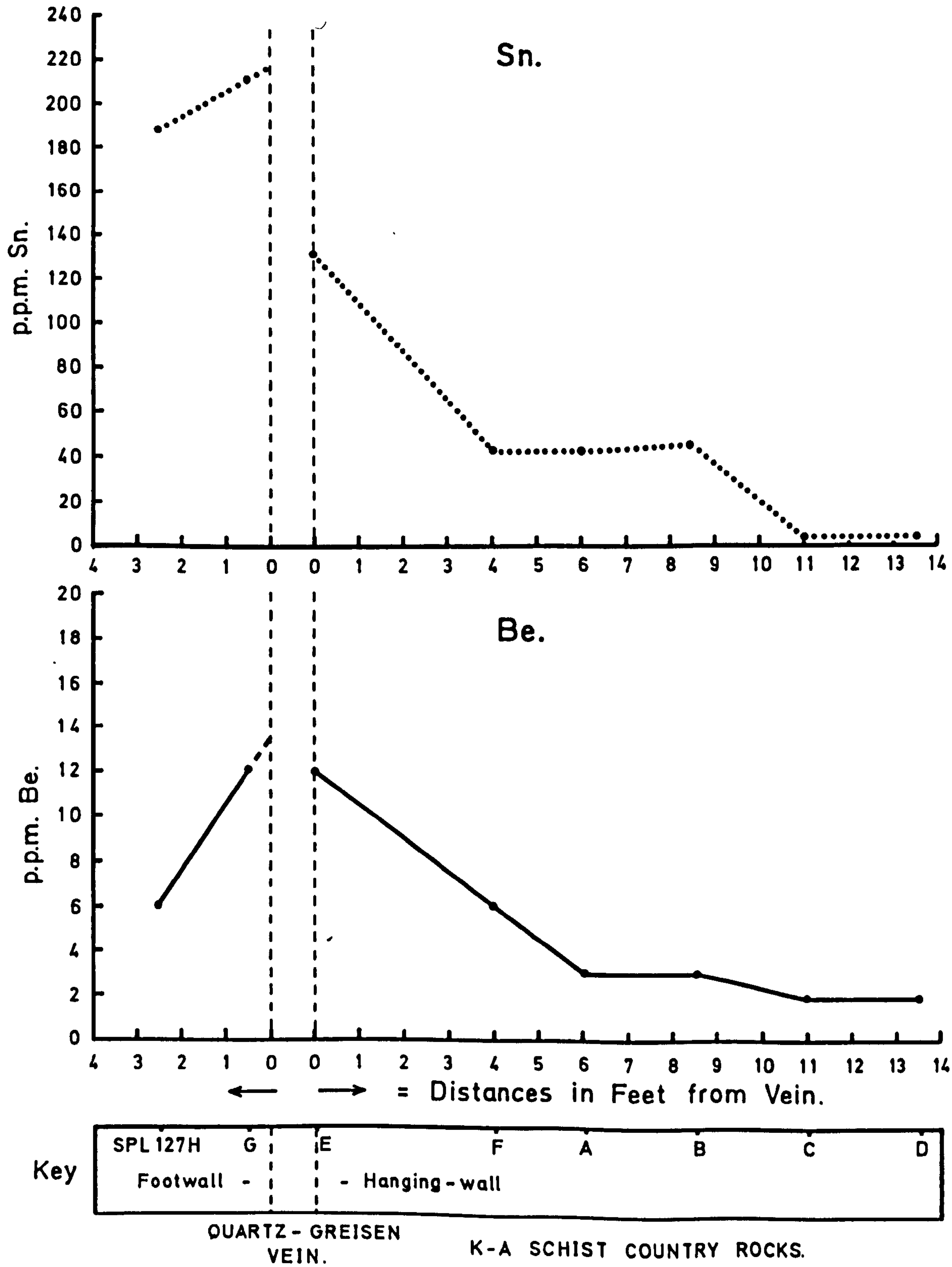
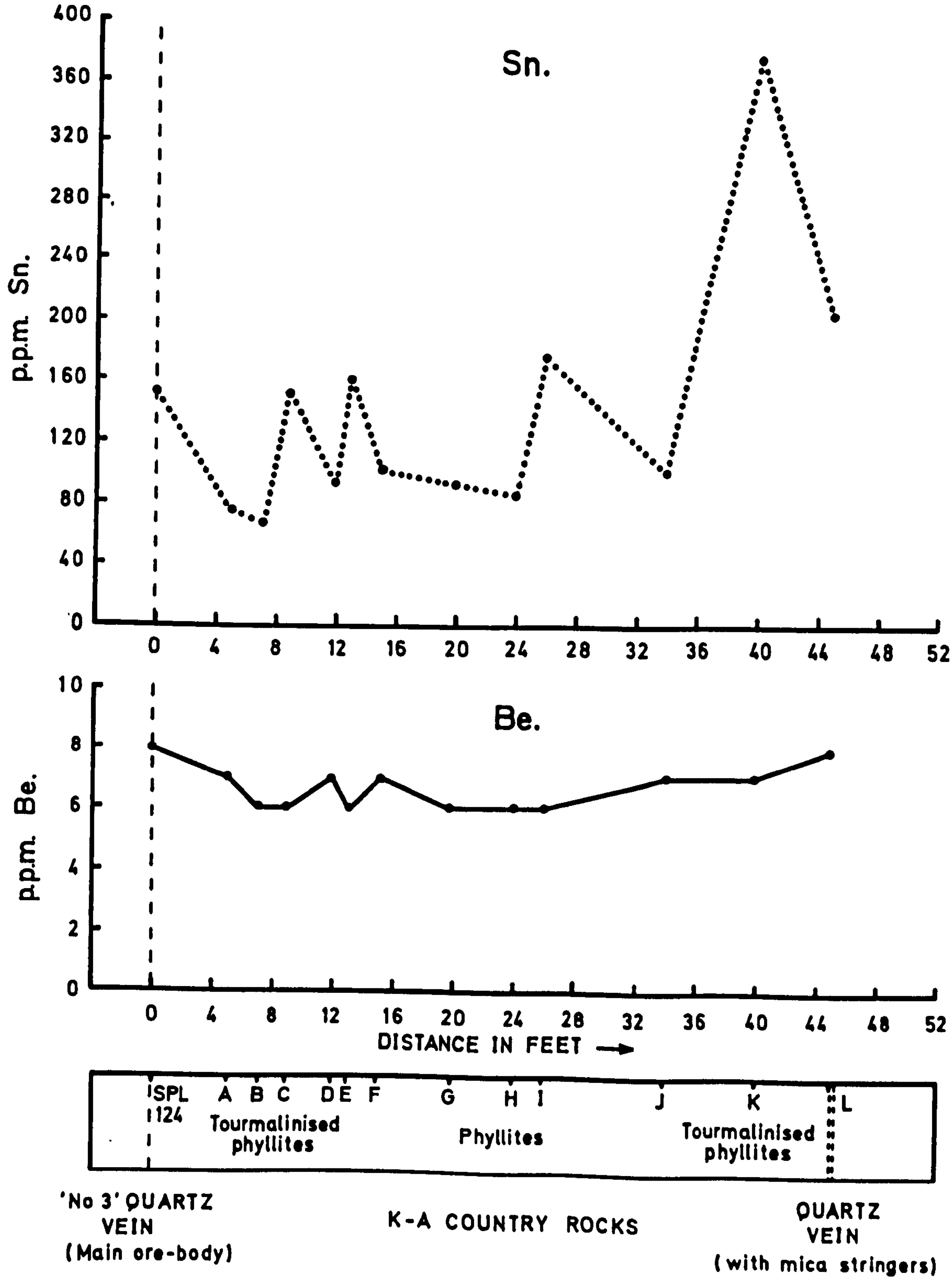


FIG 22

DISTRIBUTION OF Sn AND Be IN COUNTRY ROCKS ADJACENT TO HYDROTHERMAL CASSITERITE-BEARING VEINS AT MWIRASANDO MINE.



high concentration of tin in the rocks but reflect the presence of tin introduced along small fissures and channelways in the rocks. Two of the very high erratic values were obtained from rocks that have been particularly strongly tourmalinised. The above results indicate that the tin and beryllium were introduced into the country rocks adjacent to the mineral deposits and that the rocks probably contained average concentrations of these elements before the onset of mineralisation. The results also prove that the mineral deposits are epigenetic in origin.

CHAPTER VI

GEOCHEMISTRY OF THE POST-TECTONIC PEGMATITIC GRANITES

The Geochemistry of the Post-Tectonic Pegmatitic Granites

Results in chapter V have shown that in S.W. Ankole the post-tectonic pegmatitic granites are the only group of granitoid rocks that have been found to contain a high proportion of samples with above average tin and beryllium contents. Field evidence has shown that these granites also represent the source of the majority of granite pegmatites.

It was therefore decided to determine the chemical composition of a representative batch of pegmatitic granites in order to observe variations in the major and trace-element contents, and an attempt was made to determine whether there is any relationship between the major element and trace tin and beryllium content of the granites.

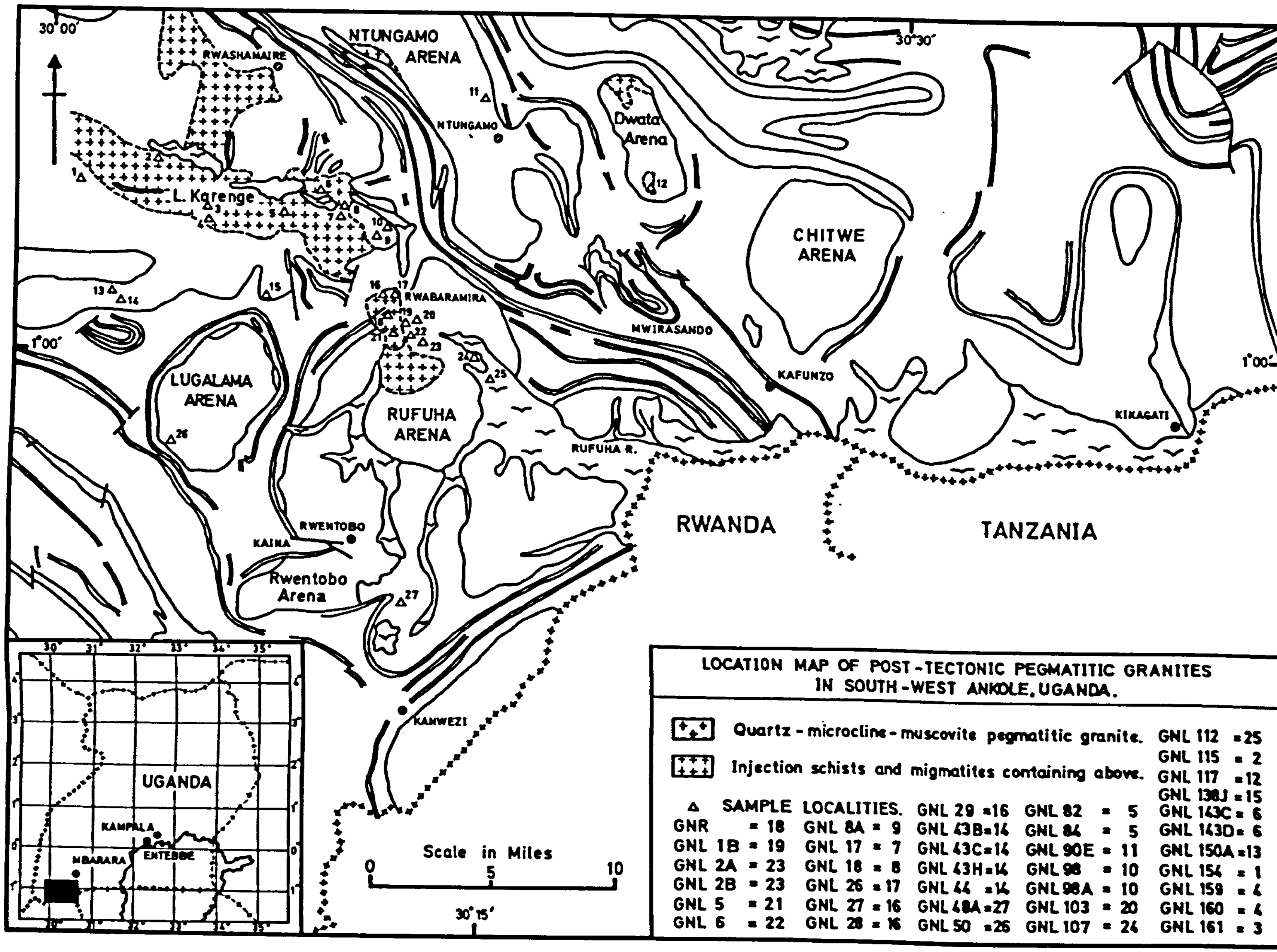
The field location and regional distribution of the pegmatitic granites studied are shown in Fig. 23 .

Fourteen samples of pegmatitic granite were analysed for ten major and minor elements using X-ray fluorescence techniques and the results appear in table 26. 38 samples of pegmatitic granite were spectrographically analysed for tin and beryllium by the Uganda Geological Survey, and tin was redetermined colorimetrically in 11 samples by the writer. The results appear in tables 27), 28.

The pegmatitic granites were found to show considerable variation in composition, particularly in their alkali content. Samples containing high potash were found to contain low soda and vice versa.

Examination of thin sections and hand specimens of samples analysed show that the samples containing high soda have been subjected to late albitisation with replacement of microcline by albite feldspar. In order to illustrate the relationship of soda to potash content of the granites, a

FIG 23



30°00′
30°30′
1°00′
1°00′
30°15′
NTUNGAMO ARENA
RWASHAMAIRE
NTUNGAMO
L. Karenge
Dwata Arena
CHITWE ARENA
RWABARAMIRA
MWIRASANDO
KAFUNZO
LUGALAMA ARENA
RUFUHA ARENA
RUFUHA R.
KIKAGATI
RWENTOBO
KAINA
Rwentobo Arena
KAMWEZI
RWANDA
TANZANIA
UGANDA
KAMPALA
ENTEBBE
MBARARA
Scale in Miles
0
5
10
LOCATION MAP OF POST-TECTONIC PEGMATITIC GRANITES IN SOUTH-WEST ANKOLE, UGANDA.
Quartz - microcline - muscovite pegmatitic granite.
Injection schists and migmatites containing above.
△ SAMPLE LOCALITIES.
GNR = 18
GNL 1B = 19
GNL 2A = 23
GNL 2B = 23
GNL 5 = 21
GNL 6 = 22
GNL 8A = 9
GNL 17 = 7
GNL 18 = 8
GNL 26 = 17
GNL 27 = 16
GNL 28 = 16
GNL 29 = 16
GNL 43B = 14
GNL 43C = 14
GNL 43H = 14
GNL 44 = 14
GNL 48A = 27
GNL 50 = 26
GNL 82 = 5
GNL 84 = 5
GNL 90E = 11
GNL 98 = 10
GNL 98A = 10
GNL 103 = 20
GNL 107 = 24
GNL 112 = 25
GNL 115 = 2
GNL 117 = 12
GNL 138J = 15
GNL 143C = 6
GNL 143D = 6
GNL 150A = 13
GNL 154 = 1
GNL 159 = 4
GNL 160 = 4
GNL 161 = 3

TABLE 26. PARTIAL X-RAY FLUORESCENCE ANALYSES OF PEGMATITIC GRANITES

Sample No.	GNL 2A	GNL 8A	GNL 18	GNL 26	GNL 27
SiO_2	73.00	73.20	75.40	75.30	73.20
TiO_2	0.03	0.04	0.06	0.04	0.04
Al_2O_3	15.18	14.81	14.75	14.77	15.27
Fe_2O_3	tr.	0.30	0.66	0.58	0.62
MnO	--	0.02	0.04	0.10	0.21
MgO	0.08	0.23	0.19	0.16	0.10
CaO	0.13	0.58	0.52	0.33	0.40
Na_2O	2.25	4.47	2.88	5.42	8.71
K_2O	9.17	6.17	6.06	2.14	1.06
P_2O_5	0.10	0.21	0.34	0.16	0.18
CO_2	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O^+	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O^-	n.d.	n.d.	n.d.	n.d.	n.d.
Total:	99.94	100.03	100.90	99.00	99.79

Table 26. Cont'd.

Sample No.	GNL 28	GNL 43C	GNL 43H	GNL 44	GNL 138J
SiO_2	75.50	72.10	69.10	70.30	68.60
TiO_2	0.04	0.03	0.03	0.03	0.03
Al_2O_3	16.29	15.99	17.28	16.35	16.29
Fe_2O_3	0.94	0.73	0.24	0.28	0.30
MnO	0.01	0.03	0.01	0.01	0.06
MgO	0.20	0.03	0.02	0.08	0.04
CaO	0.11	0.78	0.29	0.51	0.45
Na_2O	2.84	4.37	6.15	7.11	10.12
K_2O	4.44	4.90	4.70	2.97	0.51
P_2O_5	0.10	0.78	0.28	0.43	0.49
CO_2	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O^+	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O^-	n.d.	n.d.	n.d.	n.d.	n.d.
Total:	100.49	99.74	98.10	98.07	96.89

Table 26. Cont'd.

Sample No.	GNL 143D	GNL 150A	GNR	GNL 159
SiO_2	69.10	70.90	71.50	78.70
TiO_2	0.13	0.05	0.05	0.08
Al_2O_3	20.23	15.68	16.78	14.13
Fe_2O_3	2.09	0.68	0.59	1.42
MnO	0.02	0.03	0.01	0.01
MgO	0.65	0.17	0.17	0.43
CaO	0.18	0.61	0.60	0.57
Na_2O	1.22	6.99	4.72	3.37
K_2O	4.99	2.09	4.06	2.65
P_2O_5	0.04	0.54	0.07	0.05
CO_2	n.d.	n.d.	n.d.	n.d.
H_2O^+	n.d.	n.d.	n.d.	n.d.
H_2O^-	n.d.	n.d.	n.d.	n.d.
Total:	98.65	97.74	98.55	101.41

Analyst: P. Lowenstein

TABLE 27. ANALYSES OF TIN AND BERYLLIUM IN PEGMATITIC GRANITES

Rock No.	Sn ppm. (spectrographic determinatic)	Sn ppm. (colorimetric determinations)	Be ppm. (spectrographic determinations)
GNL 1B	5	-	12
GNL 2A	6	6	2
GNL 2B	5	-	3
GNL 5	5	-	2
GNL 6	5	-	8
GNL 8A	6	14	7
GNL 17	5	-	3
GNL 18	12	10	6
GNL 26	40	38	50
GNL 27	13	10	3
GNL 28	15	-	2
GNL 29	12	10	3
GNL 43B	5	-	7
GNL 43C	78	80	15
GNL 43H	68	50	100
GNL 44	38	33	58
GNL 48A	32	35	35
GNL 50	5	-	2
GNR	18	23	6

Spec. Anal.: Uganda Geol. Surv.

Col. Anal.: P. Lowenstein

TABLE 28. SPECTROGRAPHIC ANALYSES OF TIN AND BERYLLIUM IN PEGMATITIC GRANITES

Rock No.	Sn ppm.	Be ppm.	Rock No.	Sn ppm.	Be ppm.
GNL 82	5	2	GNL 143C	5	7
GNL 84	5	3	GNL 143D	20	4
GNL 90E	5	13	GNL 150A	62	135
GNL 98A	5	6	GNL 154	5	3
GNL 98	5	5	GNL 159	17	7
GNL 103	5	42	GNL 160	5	2
GNL 107	5	2	GNL 161A	20	2
GNL 115	5	2	GNL 161	5	2
GNL 117	5	7	TGNL 1A	35	82
GNL 138J	5	23			

Anal.: Uganda Geol. Surv.

variation diagram was plotted (see fig. 24) and shows that if the samples are arranged in order of decreasing potash content, the soda content rises (in spite of fairly large fluctuations) as the potash content diminishes. The rise in soda content illustrates the changes in chemical composition of the granites produced by albitisation.

No important variations in any other major element have been found although there is a slight increase in alumina content with decreasing silica content which can be observed if the samples are plotted in order of decreasing silica content (see fig. 25). The samples containing relatively high silica and low alumina have been found to contain abundant free quartz, whereas the samples containing lower silica and higher amounts of alumina are rich in feldspars and muscovite.

The albitised pegmatitic granites are of particular interest as one or two samples have been found to contain small quantities of beryl and/or cassiterite. (GN1 43C, GNL 43H, and GNL 138J). No beryl or cassiterite has been obtained from any of the unaltered pegmatitic granites and it was decided to compare the trace-tin and beryllium contents of albitised pegmatitic granites with non-albitised ones.

38 samples of pegmatitic granite which had been analysed for tin and beryllium were examined for signs of albitisation and 19 were found to have been ablitised.

12 (or 63%) of the 19 albitised granites were found to contain more than 10 ppm. of tin, and 9 (47%) of the albitised samples were found to contain more than 10 ppm of beryllium. This indicates that a large proportion of the albitised pegmatitic granites contain above average tin and beryllium.

FIG 24

VARIATION DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN Na_2O AND K_2O IN PEGMATITIC GRANITES.

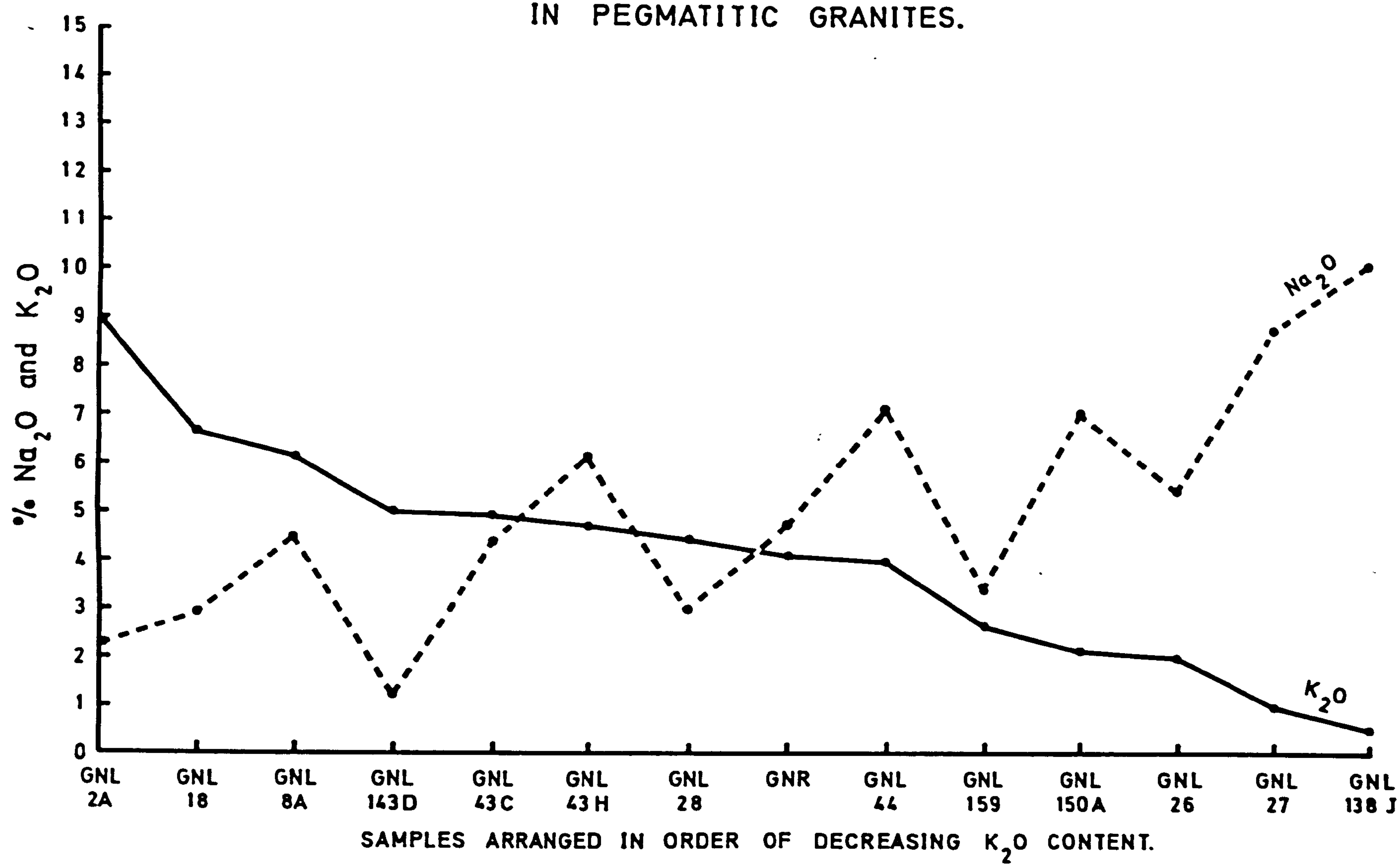
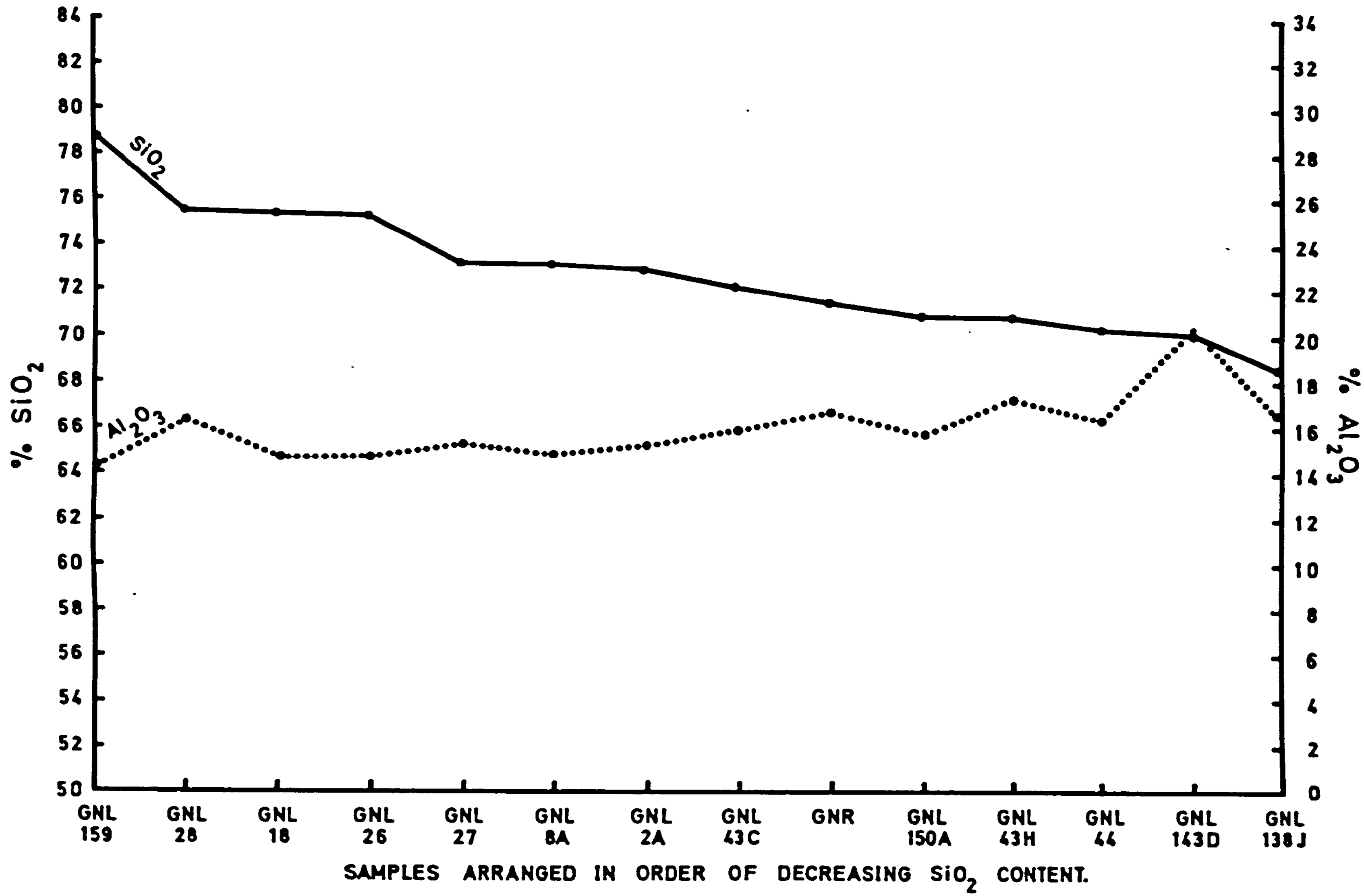


FIG 25

VARIATION DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN SiO_2 AND Al_2O_3 IN PEGMATITIC GRANITES.



In contrast only 3 (16%) of the 19 non-albitised pegmatitic granites contain more than 10 ppm. of tin and 2 (10%) of the 19 albitised granites contain more than 10 ppm. of beryllium. This indicates that a much lower proportion of non-albitised pegmatites contain more than 10 ppm. of Sn and Be than albitised ones.

The following observations have also been made:-

1. In the case of tin, 15 samples out of the total group of 38 contain > 10 ppm of Sn. Of these, 12 are albitised which means that 80% of the pegmatitic granites which contain > 10 ppm of tin have been albitised.

2. In the case of beryllium, 11 samples out of 38 contain > 10 ppm of beryllium. Of these 9 are albitised which means that 82% of the pegmatitic granites which contain > 10 ppm Be have been albitised.

The tables ~~opposite~~ (29 and 30) show the difference in chemical composition between 4 samples of strongly albitised pegmatitic granite (which contain high values of tin and beryllium), and two unaltered pegmatitic granites (which contain only low values).

<u>Summary and Conclusions</u>

The results show that a substantial proportion of the samples analysed have been albitised. Over 80% of the granites which contain > 10 ppm. Sn or > 10 ppm Be have been found to have been albitised to some degree, and this indicates that albitisation must in some way be connected with the concentration of tin and beryllium in the pegmatitic granites.

The fact that abundant beryl and some cassiterite have been found in the albitised pegmatities, indicates that albitisation must be responsible for the concentration of tin and beryllium in the pegmatites too.

TABLE 29 . CHEMICAL COMPOSITIONS OF 4 STRONGLY ALBITISED PEGMATITIC GRANITES

	GNL 43C	GNL 43H	GNL 44	GNL 150A
SiO_2	72.10	69.10	70.30	70.90
TiO_2	0.03	0.03	0.03	0.05
Al_2O_3	15.99	17.28	16.35	15.68
Fe_2O_3	0.73	0.24	0.28	0.68
MnO	0.03	0.01	0.01	0.03
MgO	0.03	0.02	0.08	0.17
CaO	0.78	0.29	0.51	0.61
Na_2O	4.37	6.15	7.11	6.99
K_2O	4.90	4.70	2.97	2.09
P_2O_5	0.78	0.28	0.43	0.54
Sn	78 ppm.	50 ppm.	38 ppm.	62 ppm.
Be	15 ppm.	100 ppm.	58 ppm.	135 ppm.

TABLE 30 . CHEMICAL COMPOSITIONS OF TWO UNALTERED PEGMATITIC GRANITES

	GNL 2A	GNL 18
SiO_2	73.00	75.40
TiO_2	0.03	0.06
Al_2O_3	15.18	14.75
Fe_2O_3	Trace	0.66
MnO	-	0.04
MgO	0.08	0.19
CaO	0.13	0.52
Na_2O	2.25	2.88
K_2O	9.17	6.06
P_2O_5	0.10	0.34
Sn	6 ppm.	10 ppm.
Be	$<$2 ppm.	6 ppm.

a. The geochemical distribution of tin in the pegmatitic granites of S.W. Ankole

Fourteen samples of pegmatitic granite which were known to contain above normal concentrations of tin (from spectrographic analyses carried out by the Uganda Geological Survey) were analysed for tin using the writers method for determining *total and acid soluble tin in rocks and minerals (see p. 222). *[The total tin content of the samples is the amount of tin released by decomposition of both rock sample and any cassiterite present in it, whereas the 'acid soluble' tin content is the amount of tin released by decomposition of the rock sample only. The nature of the soluble tin is uncertain but it may consist of lattice tin and/or soluble tin compounds such as hydrated stannic oxide].

Two types of pegmatitic granite were represented among the samples analysed-'normal' pegmatitic granites and cassiterite-bearing pegmatitic granites. The 'normal' pegmatitic granite samples represent the majority of the pegmatites of S.W. Ankole, are umineralised, and contain no trace of visible cassiterite, whereas the cassiterite-bearing pegmatitic granite samples are albitised, sometimes pass into poorly zoned pegmatite, and were collected from localities where portions of the granite contain macroscopic inclusions of cassiterite.

The 'normal' pegmatitic granites were found to contain 6-38 ppm. total tin, mainly as acid soluble tin (see table 31). In two cases however (GNL 8A and GNL 26) there was a significant difference between the total and acid soluble tin contents - indicating the possible presence of traces of cassiterite.

The cassiterite-bearing pegmatitic granites were found to contain higher concentrations of tin (33-80 ppm. total tin) and although no

TABLE 31. RESULTS OF TOTAL AND 'ACID SOLUBLE' TIN DETERMINATIONS ON PEGMATITIC GRANITES OF S.W. ANKOLE

Rock No.	Total Tin ppm.	'Acid Soluble' Tin ppm.	Difference ppm. (cassiterite)
GNL 2A	6	6	0
GNL 8A	14	5	9
GNL 18	10	10	0
GNL 25	10	8	2
GNL 26	38	25	13
GNL 27	10	6	4
GNL 29	10	10	0
GNR	23	16	7

TABLE 32. RESULTS OF TOTAL AND 'ACID SOLUBLE' TIN DETERMINATIONS ON CASSITERITE-BEARING PEGMATITIC GRANITES

Rock No.	Total Tin ppm.	'Acid Soluble' Tin ppm.	Difference ppm. (cassiterite)
GNL 43C	80	50	30
GNL 43H	50	35	15
GNL 44	33	25	8
GNL 48A	35	24	11

macroscopic cassiterite was observed in the samples analysed there was a significant difference between the total and acid soluble tin contents (see table 32) - indicating the presence of small quantities of microscopic cassiterite.

The results show that the cassiterite-bearing pegmatitic granites contain higher concentrations of tin than the 'normal' pegmatitic granites, and suggest that even in the absence of macroscopic cassiterite, very fine grained cassiterite can account for a small proportion of the total tin present.

b. Distribution of Tin in Minerals from the Pegmatitic Granites

As part of the study of the occurrence of tin in the pegmatitic granites it was decided to separate muscovites, biotite, microcline feldspar, and quartz from the granites and analyse these minerals for tin.

Muscovites

11 samples of muscovite were separated from the pegmatitic granites and were analysed for total and acid soluble tin. These included 7 micas from 'normal' pegmatitic granites and 4 from the cassiterite-bearing pegmatitic granites. The muscovites separated from the 'normal' (non-cassiterite-bearing) pegmatitic granites were found to contain 18-125 ppm of total tin of which most was 'acid soluble' (see table 33). In three cases there was a small difference between the total and soluble tin contents indicating the presence of traces of cassiterite.

The micas from the cassiterite-bearing pegmatitic granites were found to contain much higher concentrations of total tin (350-600 ppm) which included up to 75 ppm of cassiterite (see table 34).

Comparison of the tin contents of the muscovites with those of the granites from which they were separated (see tables 35&36) shows that up to a 14-fold concentration of tin has occurred in the muscovites, and that the muscovites must contain the bulk of the tin present in the rocks.

The large difference in total tin content between muscovites from the 'normal' pegmatitic granites and the cassiterite-bearing granites suggests that muscovite could be used as a prospecting guide in searching for cassiterite-bearing pegmatitic granites.

Biotite

Biotite is very rare in the pegmatitic granites but one small sample (0.25g.) was separated from GNL 29 and was analysed for 'acid soluble' tin.

TABLE 33. RESULTS OF TOTAL AND 'ACID SOLUBLE' TIN DETERMINATIONS ON MUSCOVITES SEPARATED FROM PEGMATITIC GRANITES

Muscovite No.	Total Tin ppm.	'Acid Soluble' Tin ppm.	Difference ppm. (cassiterite)
GNL 14 M	18	13	5
GNL 18 M	100	88	12
GNL 25 M	50	50	0
GNL 26 M	125	125	0
GNL 27 M	100	75	25
GNL 28 M	60	50	10
GNL 29 M	35	30	5

TABLE 34. RESULTS OF TOTAL AND 'ACID SOLUBLE' TIN DETERMINATIONS ON MUSCOVITES FROM TIN BEARING PEGMATITIC GRANITE VEINS

Muscovite No.	Total Tin ppm.	'Acid Soluble' Tin ppm.	Difference ppm. (cassiterite)
GNL 43 C/M	550	500	50
GNL 43 H/M	600	600	0
GNL 44 M	450	450	0
GNL 48 A/M	350	275	75

TABLE 35. TO SHOW DEGREE OF CONCENTRATION OF TIN IN MUSCOVITES SEPARATED FROM PEGMATITIC GRANITES

Rock No.	Total Tin ppm.	Mica No.	Total Tin ppm.	Concentration factor
GNL 14	10	GNL 14 M	18	1.8
GNL 18	10	GNL 18 M	100	10.0
GNL 25	10	GNL 25 M	50	5.0
GNL 27	10	GNL 27 M	100	10.0
GNL 28	20	GNL 28 M	60	3.0
GNL 29	10	GNL 29 M	35	3.5

TABLE 36. TO SHOW DEGREE OF CONCENTRATION OF TIN IN MUSCOVITES SEPARATED FROM CASSITERITE-BEARING PEGMATITIC GRANITES

Rock No.	Total Tin ppm.	Mica No.	Total Tin ppm.	Concentration factor
GNL 43 C	80	GNL 43 C/M	550	6.1
GNL 43 H	50	GNL 43 H/M	600	12.0
GNL 44	33	GNL 44/M	450	13.6
GNL 48 A	35	GNL 43/M	350	10.0

The result obtained was 63 ppm. (Unfortunately there was insufficient material available to enable a total tin determination to be obtained as well).

The result for 'acid soluble' tin does nevertheless show that a high concentration of tin has occurred in the biotite. The tin content of the biotite (63 ppm) is almost double that of muscovite from the same granite (35 ppm), and almost six times the value obtained for the rock as a whole (10 ppm).

Microcline feldspar

Microcline feldspar was separated from two pegmatitic granites (GNL 27 and GNL 29) and the feldspars were analysed for total tin. The tin contents were found to be 5 ppm. and 5 ppm. respectively.

The granites from which the feldspars were separated both contain 10 ppm of total tin and the results show that tin is not concentrated in the K- feldspars.

Quartz

Two samples of quartz from granites GNL 27 and GNL 29 were analysed for tin and were found to contain none.

Conclusions

Tin determinations on minerals separated from pegmatitic granites show that in the majority of cases the bulk of the tin present in the granites must be concentrated in the muscovites. The tin content of the muscovites can also be used to distinguish between cassiterite-bearing and non-cassiterite-bearing granites.

This supports observations made by Popolitov, E.I. (1964), who states that the tin content of muscovites from ore-bearing (cassiterite) pegmatites is considerably larger than that in muscovites from veins containing no cassiterite but contradicts data presented by Jedwab, J. (1953) who claims that the amount of tin present in micas from cassiterite-bearing pegmatites is about equal to that of muscovite from non-cassiterite-bearing pegmatites.

Ther writer believes that the tin content of muscovites can be used to distinguish between cassiterite-bearing and non-cassiterite-bearing granites, especially if traces of cassiterite can be shown to account for a proportion of the total tin present.

The relatively high tin content of the biotite in the pegmatitic granite GNL 29 (with respect to the other rock-forming minerals) is interesting and shows that when biotite occurs in addition to muscovite in a granite, the biotite contains the highest concentration of tin.

This is in agreement with observations made by several other workers: Ahrens, L.H. and Liebenberg, W.R. (1950), Barsukov, V., and Pavlenko, L.I., (1956), Barsukov, V.L. (1958), Grigor'ev, Iv.F. and Dolmamova, E.I. (1964), Jedwab, J. (1957), and Rattigan, J.H. (1963), who all state that biotites are the main accumulators of tin amoung the rock-forming minerals in granitic rocks (particularly in biotite granites).

Some of these workers also suggest that the tin content of biotites can be used in distinguishing tin-bearing from non-tin-bearing granites. The great scarcity of biotites in the pegmatitic granites(which are the only granites in S.W. Ankole in which concentration of tin has occurred), has prevented the writer from making similar comparisons.

CHAPTER VII

THE ORIGINS OF THE TIN AND BERYLLIUM WHICH ACCUMULATED IN THE MINERAL DEPOSITS

Discussion of the origins of the tin and beryllium which accumulated in the mineral deposits of S.W. Ankole

It has been established that in the majority of cases only rocks that have been subjected to post-tectonic palingenesis, hydrothermal or metasomatic alteration have been found to contain above average concentrations of tin and beryllium. The mineral deposits of S.W. Ankole have been shown to be epigenetic in origin and their formation has resulted in the introduction of tin and beryllium into adjacent wall rocks.

Unaltered granitoid and sedimentary rocks have nearly all been found to contain average abundances of tin and beryllium for these rocks in the earth's crust and the question is raised as to a possible source of these two elements.

1. The origin of tin (and beryllium) in the hydrothermal mineral deposits

Various workers (Barsukov 1957, Ivanova 1963, and Rattigan 1963) studying other areas containing tin deposits, have been able to recognise the presence of tin-bearing granites which contain approximately 15-30 ppm of tin and are directly associated with the mineralisation, and have been able to distinguish these from non-tin-bearing granites which only contain 3-5 ppm of tin and are not associated with any mineralisation. Barsukov explains the mineralisation associated with the tin-bearing granites as being due to albitisation of the tin bearing granite during which biotite is converted to muscovite, releasing most of the tin to post-magmatic alkaline solutions.

In S.W. Ankole it has unfortunately not been possible to recognise the presence of any substantial areas of granitoid rocks which could be classed as tin-bearing granites, and the majority of the arena 'granites' around which the tin deposits are distributed, have been found to contain only average abundances of tin.

The only exceptions that have been found are the 'granites' in the Ibanda Arena (Uganda) and (at Kasanyi) in the Sina Arena (N.E. Tanzania), which have been found to contain 17-30 ppm. of Sn. It is possible that the tin deposits at Kikagati and other places surrounding the Ibanda Arena, and the tin deposits at Kyerwa and other places around the Sina Arena could have been derived from these granites, but the absence of tin from most of the other arena granites in S.W. Ankole makes the presence of the tin deposits at Mwerasando, Nyamaherere, Kaina and Burama Ridge very difficult to explain.

At Kyerwa (adjacent to the Sina Arena), there is little problem in explaining the presence of tin deposits. The Kasanyi granite is tin-bearing, has suffered muscovitisation and locally albitisation, and the tin deposits were probably formed from tin-bearing hydrothermal fluids derived by post-magmatic alteration of the granite.

The tin deposits surrounding the Ibanda granite are more difficult to explain as although the granite contains tin, no muscovitisation or albitisation (which are necessary to release the tin) has been observed at the levels now exposed. It is possible however that the tin deposits were formed by hydrothermal fluids derived by metasomatic alteration (i.e. albitisation and muscovitisation) or melting of the granite at depth. The origin of the tin which occurs in the deposits situated around the other arena granites (which are non tin-bearing) is much more difficult to explain. The tin deposits have been found to occur only where K-A sediments lie in sharp contact with the arena 'granites' (granodiorites in most cases). At Kaina the granodiorite adjacent to the K-A sediments which contain tin deposits has suffered hydrothermal alteration and contains slightly higher concentrations of tin than the unaltered granodiorite.

fig 26

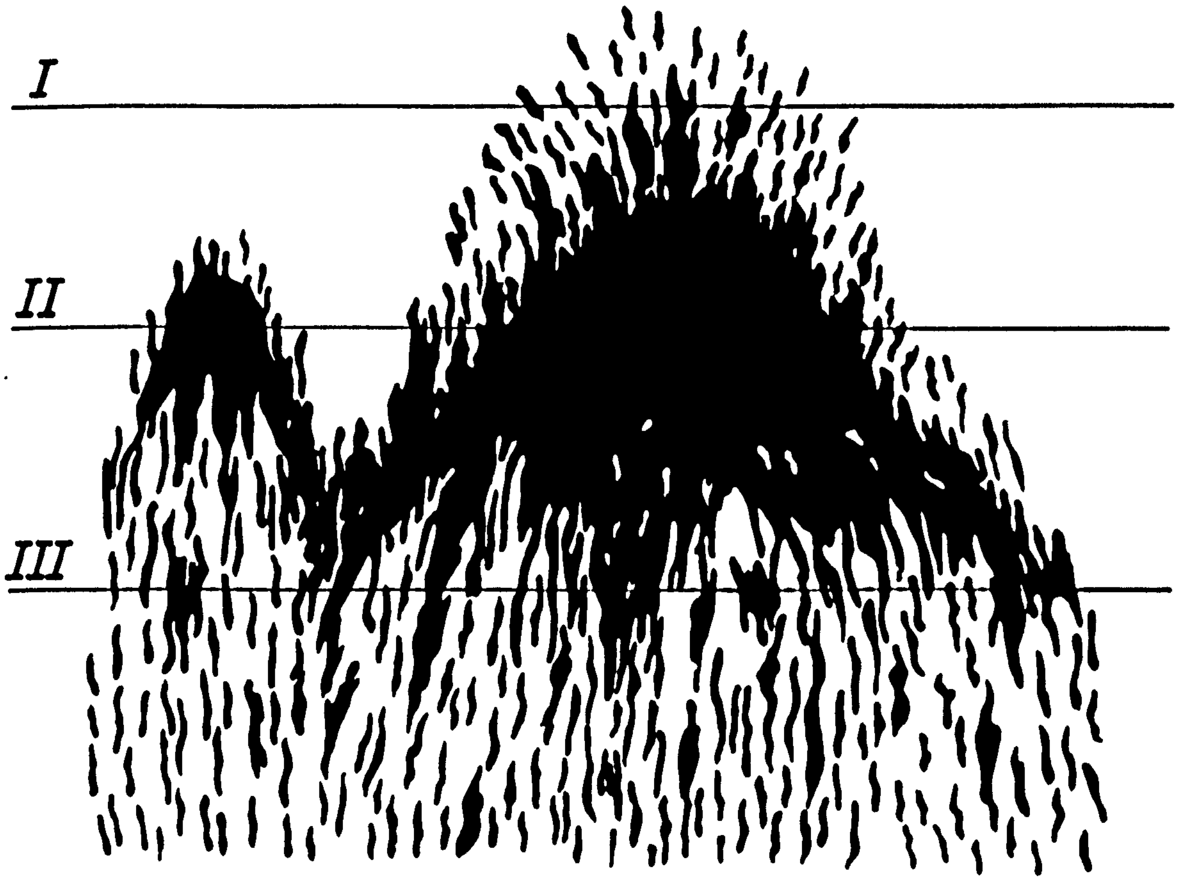


Diagram illustrating N.H. Magnusson's views on the relationship between the veined gneisses and the younger granites and granite pegmatites of Sweden.

It is believed that the tin which formed the Kaina (and other hydrothermal deposits) was not derived from the granodiorites at present exposed but was introduced from depth by hydrothermal fluids which ascended the contacts between the granodiorites and the adjacent sediments. The presence of a massive quartz dyke containing tin-bearing mica-rock inclusions between the granodiorite and K-A sediments at Kaina supports the theory that tin-bearing fluids were introduced along the contact.

It is suggested that the tin (beryllium and other elements which accumulated in the hydrothermal tin deposits) was derived from granitoid rocks situated at greater depths in the Kibaran belt.

2. <u>The origin of tin and beryllium in the granite pegmatites</u>

The granite pegmatites of S.W. Ankole show a close association with major exposures of post-tectonic pegmatitic granite and have been derived from magma produced by potash metasomatism and palingenesis of pre-existing granitoid rocks.

The circumstances which resulted in the formation of the post-tectonic pegmatitic granites and pegmatites in S.W. Ankole are believed to be very similar to those presented by N.H. Magnusson (1965) for the Pre-Cambrian younger granites in Sweden.

The opposite diagram (fig.26) illustrates Magnussons' views on the relationship between the veined gneisses and the younger (post-tectonic) granites and pegmatites associated with them. The black veins in the lower part of the diagram (level III) represent granitic material soaking the veined gneisses. This material collected later at a higher level (II) into granite masses, from which pegmatitic material was later injected into the overlying country rocks, (level ~~III~~ I).

An analogous situation occurs in S.W. Ankole. The pegmatites and pegmatitic granites (which occur in granitoid country rocks) tend to be restricted to areas of very inhomogeneous gneisses, migmatites and foliated granites and occur at level III in Magnusson's diagram.

The Rwabaramira post-tectonic pegmatitic granite intrusion which lies in contact with K-A schists and phyllites occurs at level II, and the granite pegmatites which occur in the K-A sediments to the N. of the Rwabaramira intrusion occur between levels I and II.

It will be apparent from the diagram that the granite magma which formed the pegmatitic granites and the pegmatites was derived from pre-existing granitoid rocks that were undergoing palingenesis and soaking by granitic material. The tin, beryllium and other elements which concentrated in the pegmatitic granites and pegmatites were derived from the same source.

CHAPTER VIII

THE MECHANISMS OF TRANSPORT OF TIN DURING THE FORMATION OF THE MINERAL DEPOSITS

The Mechanisms of Transport of Tin during formation of the Mineral Deposits of S.W. Ankole

In chapter VI. it has been established that there is a close relationship between albitisation and the deposition of beryl in the pegmatites and pegmatitic granites of S.W. Ankole. It is therefore possible that the soda-bearing fluids which caused albitisation may also have been responsible for the formation of cassiterite and beryl.

This theory is supported by evidence presented by M.F. Strelkin (1939) for the formation of cassiterite in pegmatites. Strelkin states that cassiterite in pegmatites is formed as a result of the hydrolysis of alkali stannates:-

$$Na_2SnO_3 + H_2O \longrightarrow SnO_2 + 2NaOH$$

and that this is accompanied by the alteration of K-feldspars by NaOH solutions which are formed during hydrolysis of the stannates.

The close association of cassiterite and albite in the pegmatites and pegmatitic granites of S.W. Ankole strongly suggests that tin was transported by and deposited from fluids containing sodium stannate or some other sodium-bearing tin complex.

Tin has however also been deposited (as cassiterite) in large amounts in hydrothermal and quartz-mica deposits which contain no albite, and the question is raised as to the form in which tin was transported during formation of these deposits.

In 1932 W.C. Simmons suggested that the tin (in the hydrothermal deposits of S.W. Ankole) was transported in the form of potassium stannate $K_2O.SnO_2.3H_2O$ and that on meeting silica, tin was deposited as stannic oxide, (cassiterite) and the alkalis were incorporated with alumina, in muscovite.

$$K_2O.SnO_2.3H_2O + 6SiO_2 + 3Al_2O_3 \longrightarrow K_2O.2H_2O.3Al_2O_3.6SiO_2 + SnO_2 + H_2O$$

The evidence derived from the pegmatites however favours the transport of tin as sodium stannate and the possibility is raised that the tin in the hydrothermal veins could also have been transported in the form of a sodium containing tin complex.

As the hydrothermal tin veins all contain muscovite (which can accomodate sodium in the crystal lattice) it was decided to study the composition of muscovites from the tin veins to determine whether they contain sodium or any other alkalis likely to have assisted transport of tin in the hydrothermal fluids. Muscovites from other deposit types were also analysed to determine whether their composition differed significantly from those obtained from the hydrothermal tin veins.

Over 86 samples of fresh muscovite-bearing material were collected from a variety of sources which include:-

a. Hydrothermal quartz-cassiterite-bearing veins

b. Quartz mica veins

c. "Greisen" and micarock units in granite pegmatites

d. Granite pegmatites

e. Post-tectonic pegmatitic granite

The muscovite samples were subjected to careful preparation which included disaggregation, separation, cleaning and comminution, to produce pure powders with a maximum particle size of - 150 mesh. The procedure for sample preparation is described in appendix III.

The powdered muscovite samples were analysed for the five alkalis - lithium, sodium, potassium, rubidium and caesium.

Sodium and potassium were determined in two separate batches of samples using two different techniques. The first batch of 29 samples was analysed using flame photometry and these samples were then used as standards to determine the same elements in a second batch of 62 samples, by X-ray fluorescence analysis.

Rubidium and caesium were determined by X-ray fluorescence analysis and lithium was determined spectrographically (using potassium as a variable internal standard). For details of the analytical procedures see appendix p. 219.

The results of the analyses are presented in tables 44 . (see appendix). In order to evaluate the results the muscovites were divided into 5 main (genetic) groups.

1. Muscovites from pegmatitic granites.
2. Muscovites from granite pegmatites (excluding late mica rock or greisen units).
3. Muscovites from quartz mica veins and "greisen" or mica rock units in pegmatites.
4. Muscovites from hydrothermal quartz-cassiterite-bearing veins.
5. Lithian muscovites from pegmatites.

The results obtained for each of the 5 alkalis for muscovites from each of the five main groups were plotted on histograms from which the range of alkali values for each group could be observed and the arithmetic mean for each group was calculated. In addition histograms were plotted for $Na_2O + Rb_2O + Cs_2O$ and $Rb_2O + Cs_2O$. (see figs. 27 – 33).

A study of the histograms shows that each group of muscovites has a different distribution of alkalis and that the range of alkali contents varies considerably from group to group.

The most interesting fact to emerge is that the muscovites from the hydrothermal tin veins contain the highest concentrations of sodium (up to

Key to the histograms showing the distribution of tin, alkalis and fluorine in muscovites from the mineral deposits and pegmatitic granites of S.W. Ankole

Group 1.	Muscovites from pegmatitic granites.
Group 2.	Muscovites from granite pegmatites (excluding late mica-rock or 'greisen' units).
Group 3.	Muscovites from quartz mica veins and 'greisen' or mica rock units in pegmatites.
Group 4.	Muscovites from hydrothermal quartz cassiterite-bearing veins.
Group 5.	Lithian muscovites from pegmatites.

FIG 27

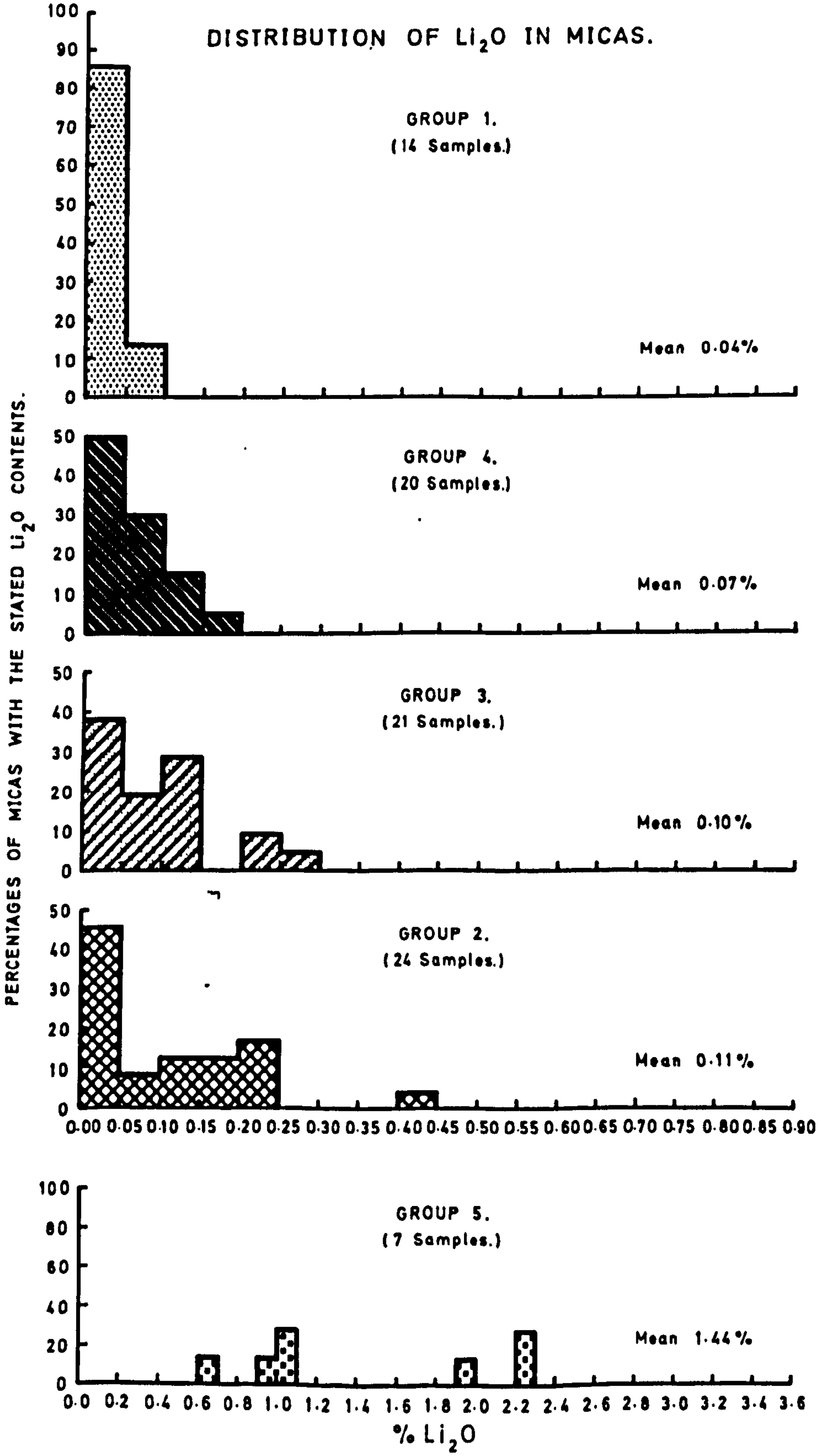

DISTRIBUTION OF Li_2O IN MICAS.
PERCENTAGES OF MICAS WITH THE STATED Li_2O CONTENTS.
GROUP 1.
(14 Samples.)
Mean 0.04%
GROUP 4.
(20 Samples.)
Mean 0.07%
GROUP 3.
(21 Samples.)
Mean 0.10%
GROUP 2.
(24 Samples.)
Mean 0.11%
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90
GROUP 5.
(7 Samples.)
Mean 1.44%
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6
% Li_2O

FIG 28

DISTRIBUTION OF Na_2O IN MICAS.

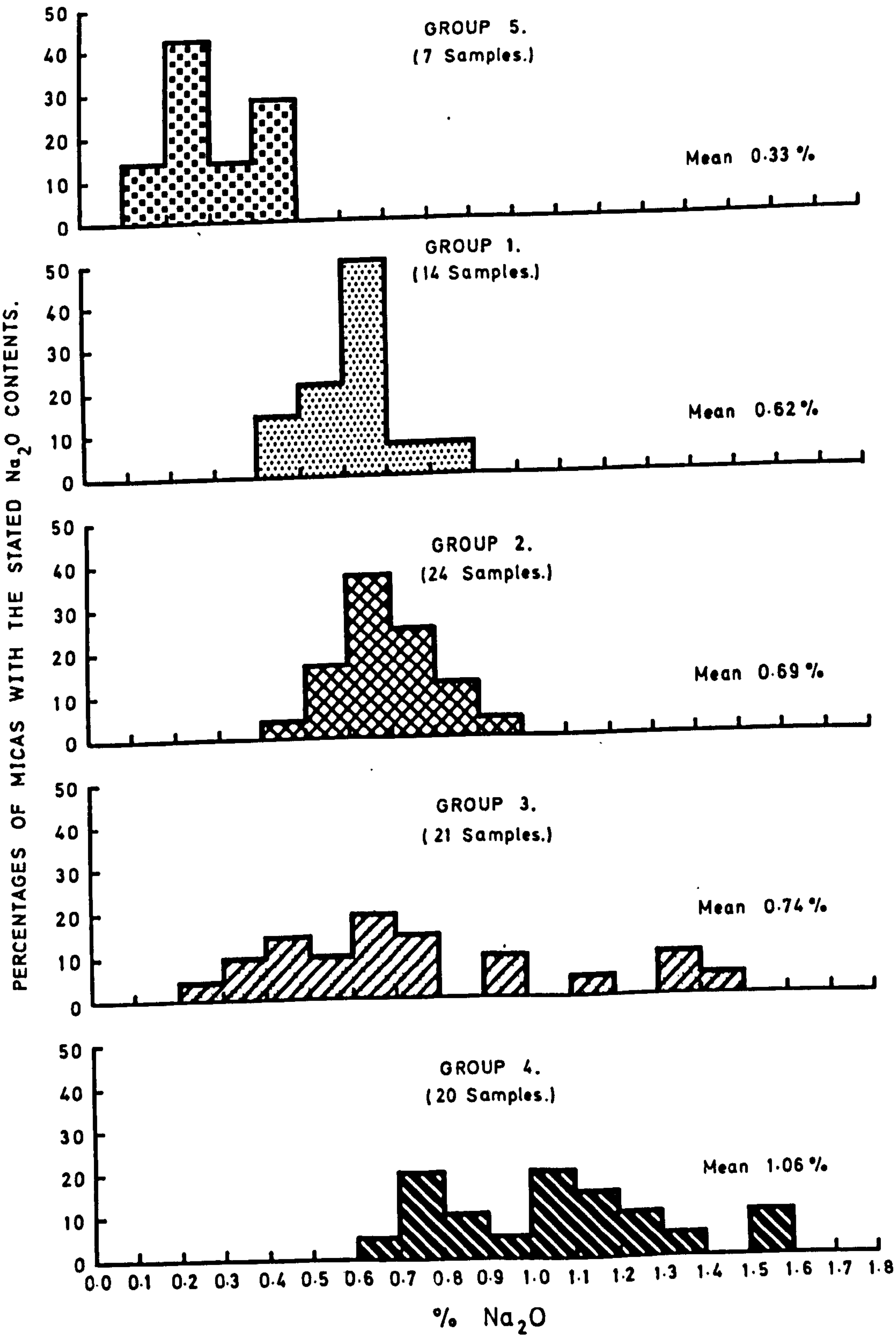


FIG 29

DISTRIBUTION OF K_2O IN MICAS.

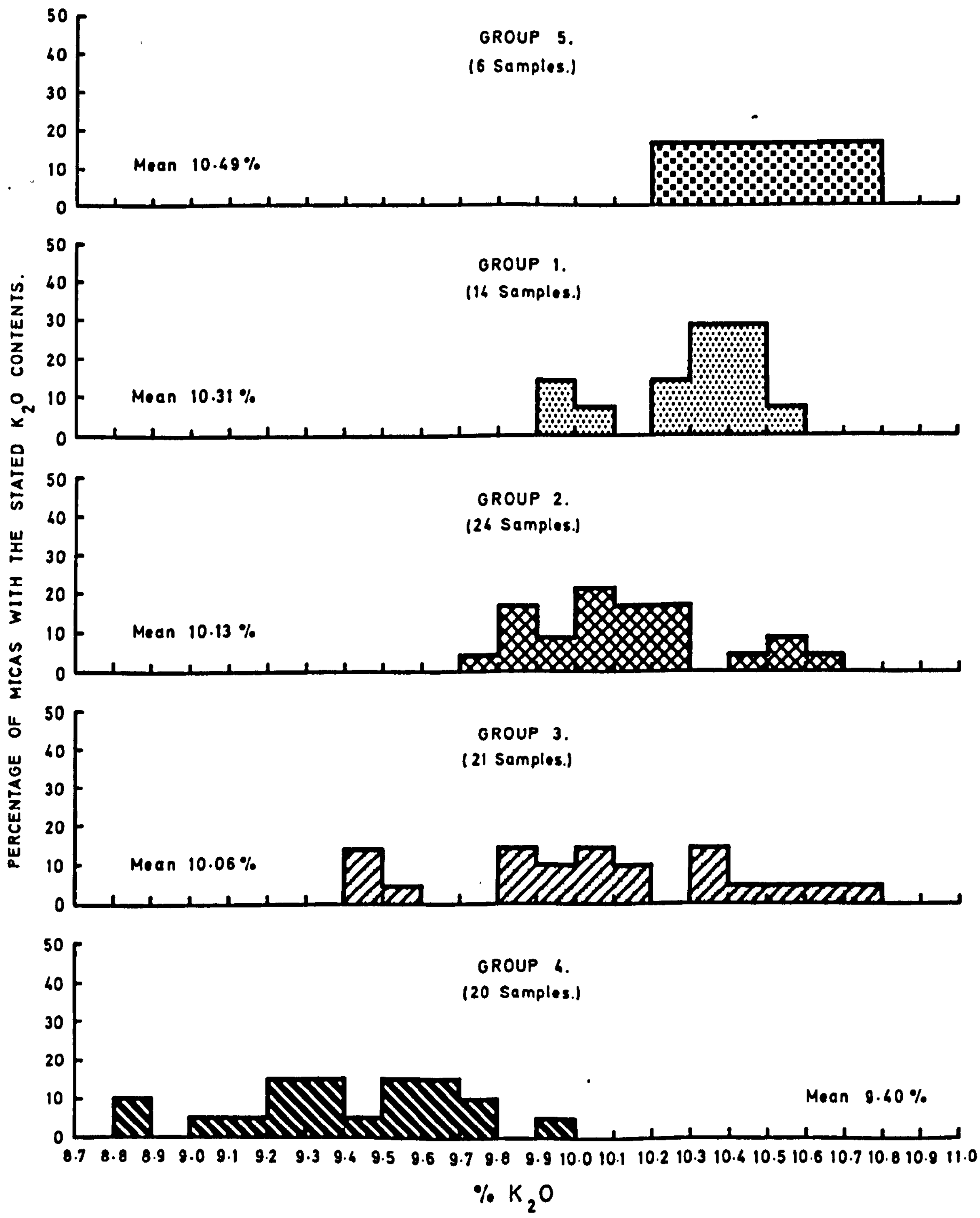


FIG 30

DISTRIBUTION OF Rb_2O IN MICAS.

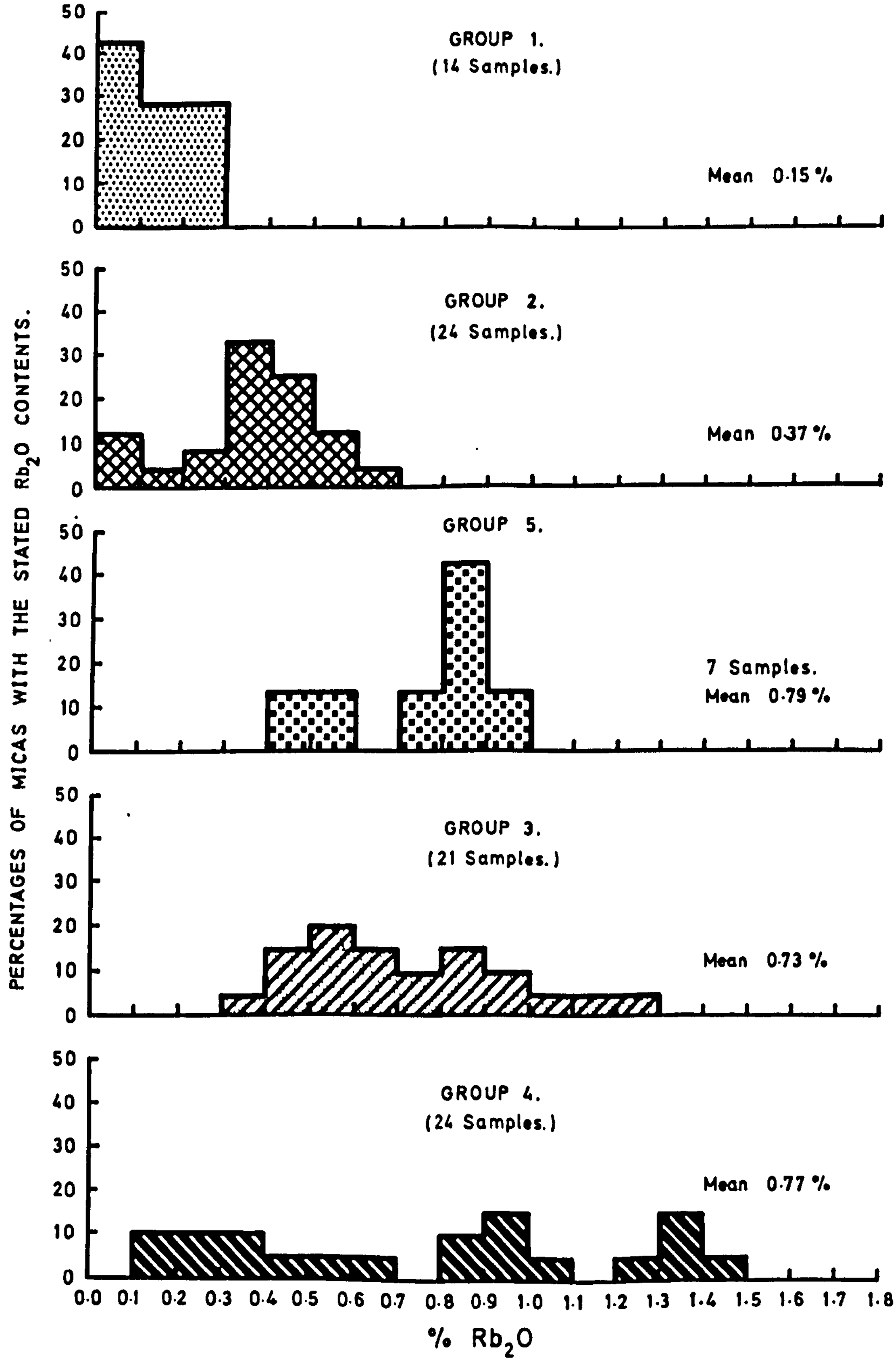


FIG 31

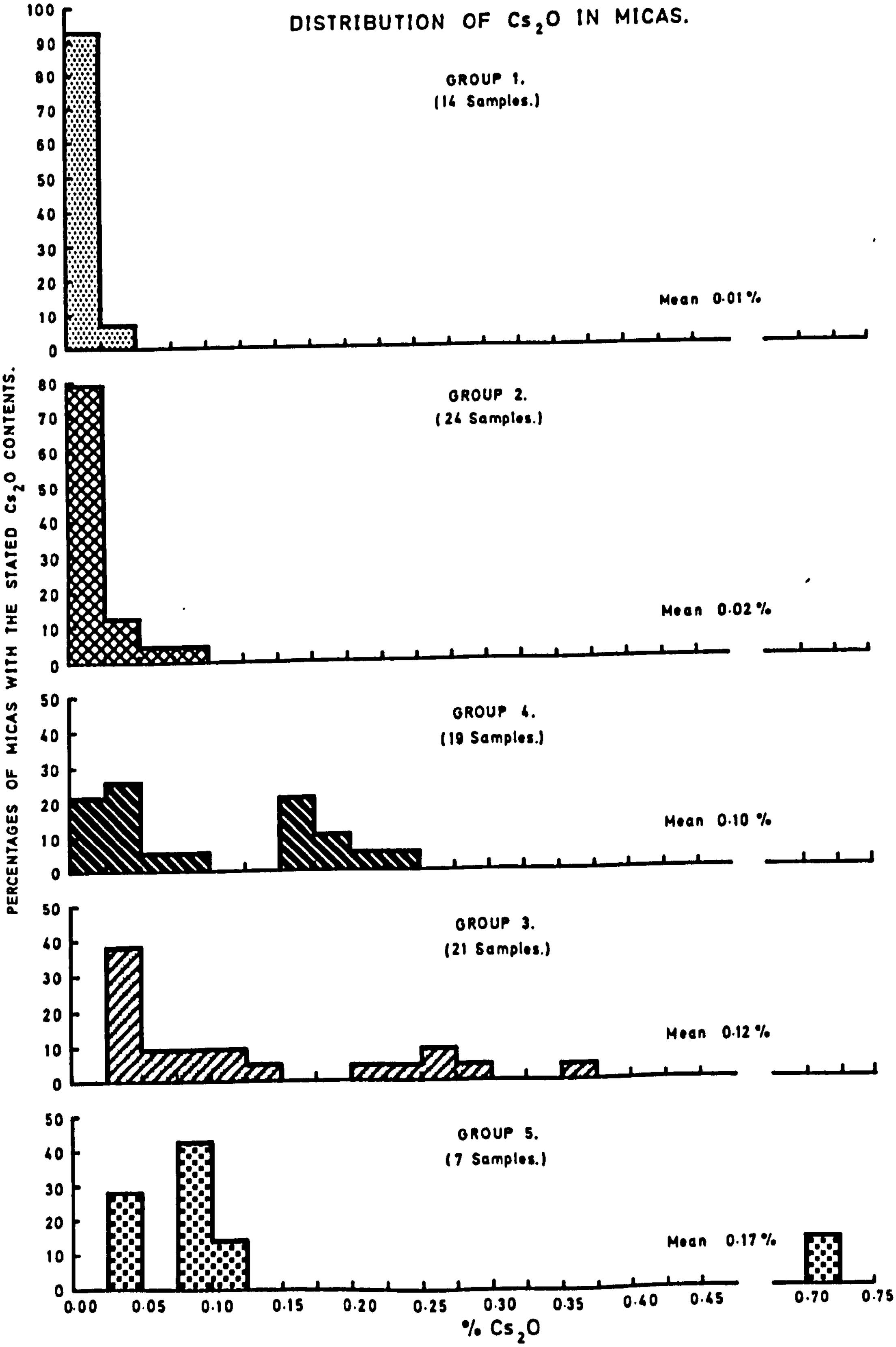

DISTRIBUTION OF Cs_2O IN MICAS.
GROUP 1.
(14 Samples.)
Mean 0·01 %
GROUP 2.
(24 Samples.)
Mean 0·02 %
GROUP 4.
(19 Samples.)
Mean 0·10 %
GROUP 3.
(21 Samples.)
Mean 0·12 %
GROUP 5.
(7 Samples.)
Mean 0·17 %
PERCENTAGES OF MICAS WITH THE STATED Cs_2O CONTENTS.
0·00 0·05 0·10 0·15 0·20 0·25 0·30 0·35 0·40 0·45 0·70 0·75
% Cs_2O

FIG 32

DISTRIBUTION OF COMBINED Rb_2O AND Cs_2O IN MICAS.

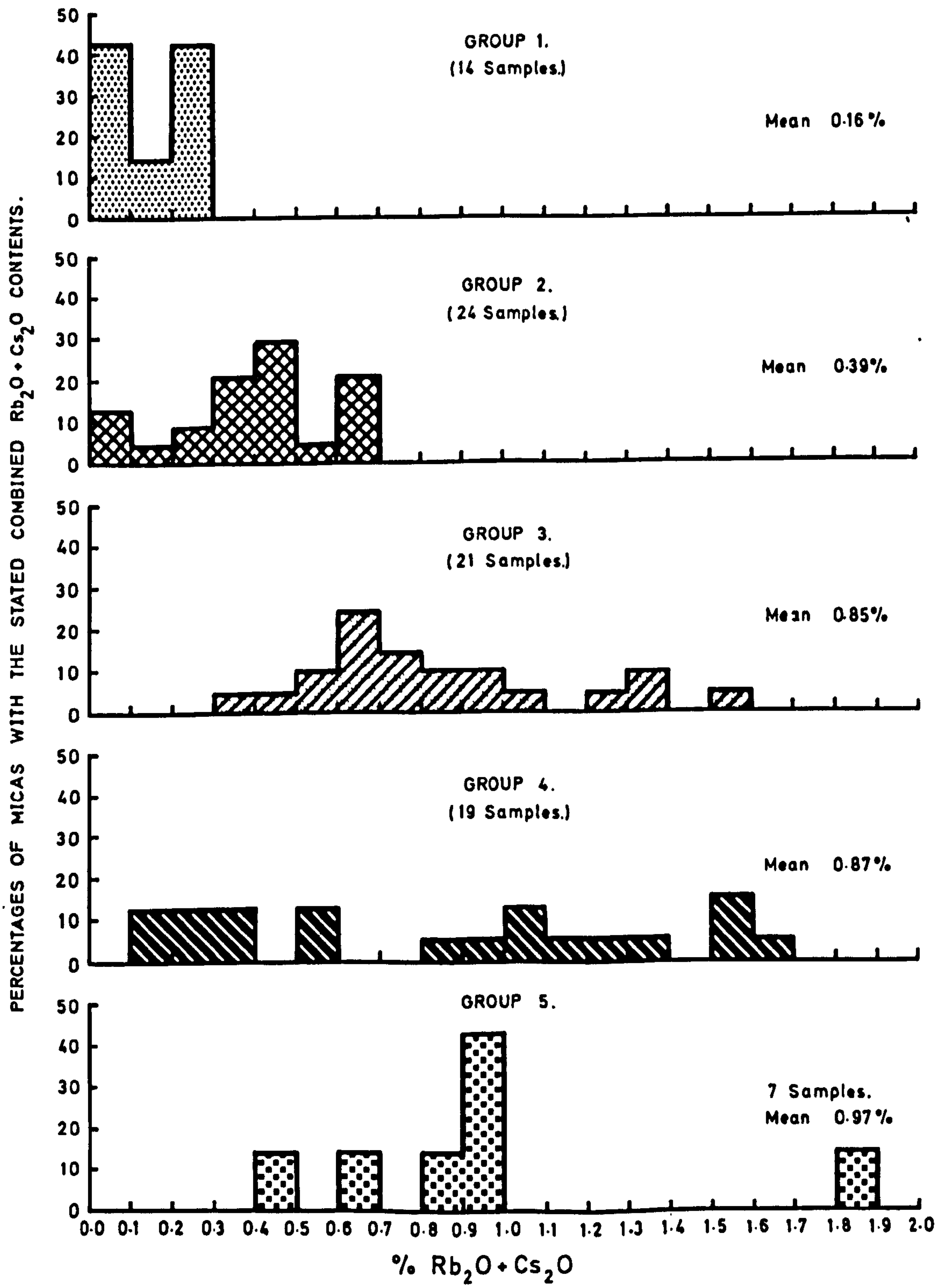
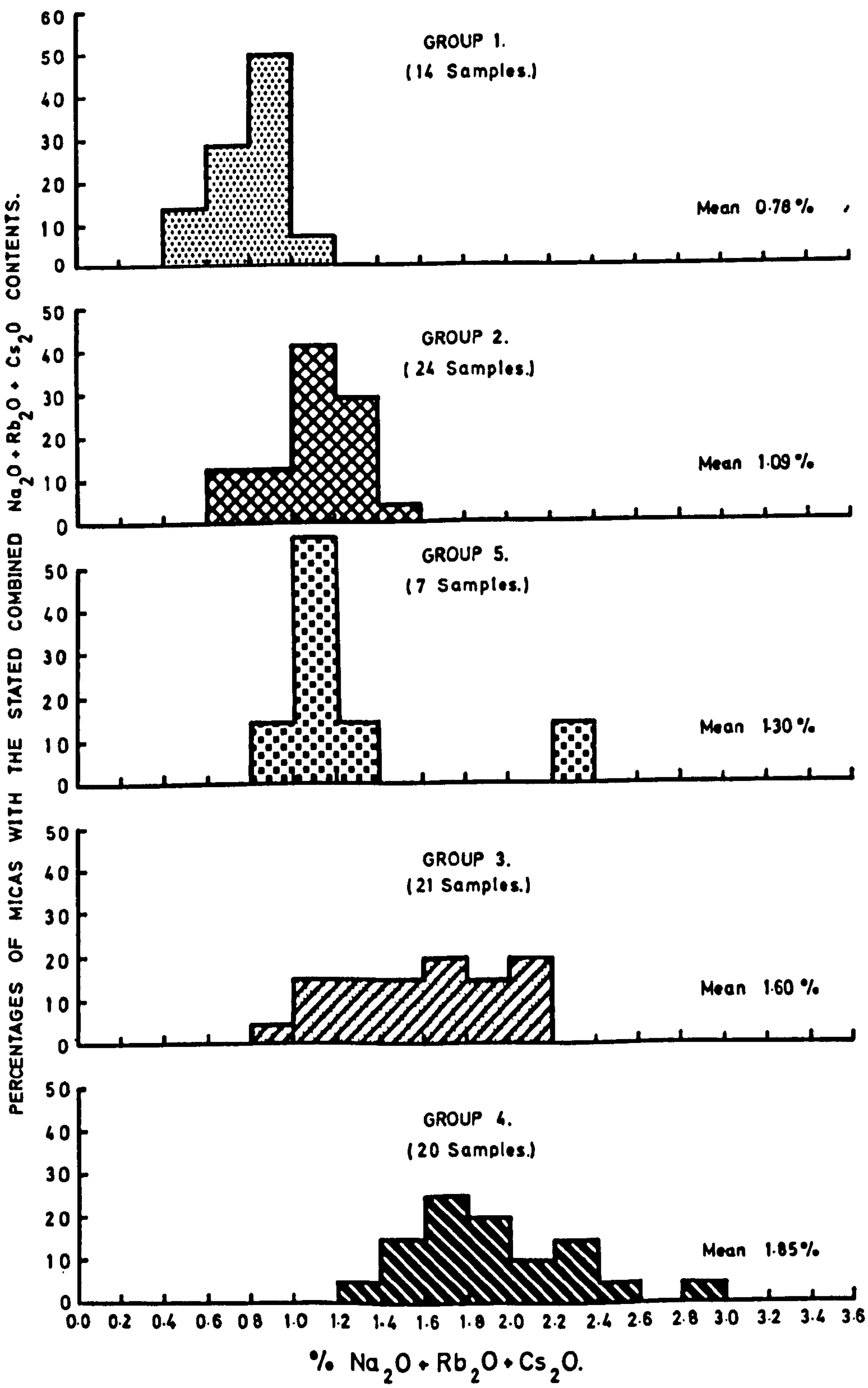


FIG 33

DISTRIBUTION OF COMBINED Na_2O, Rb_2O AND Cs_2O IN MICAS.



1.6% Na_2O and the lowest concentrations of potassium (down to 8.8% K_2O) of any of the groups.

The muscovites from the hydrothermal tin veins have also been found to contain a very wide range of rubidium Rb_2O concentrations (0.1 - 1.5%). The presence of 1.5% Rb_2O is unusual for muscovite.

The histogram showing combined $Na_2O + Rb_2O + Cs_2O$ shows that the muscovites from the hydrothermal tin veins also contain higher total values for these elements than any other group of micas (including the lithian muscovite from the granite pegmatites).

It is the writer's opinion that the high concentration of Na_2O and combined $Na_2O + Rb_2O + Cs_2O$ is significant and may reflect the role of these alkalis as transporting agents for tin in the hydrothermal deposits.

The possibility that K^+ acted as the transporting agent cannot be ruled out but the constant association of cassiterite with albite in the granite pegmatites (see p. 68) indicates that Na^+ may be the most important alkali in the transport of tin.

Lithium, (which owing to its small ionic radius behaves differently from any of the other alkalis) has not been found to be concentrated in muscovites from any of the hydrothermal deposits and has only been found in lithian muscovite produced at a late stage in the granite pegmatites. This alkali is not believed to have been directly involved in the transport of tin in the hydrothermal veins and granite pegmatites of S.W. Ankole, although in many other parts of the world lithium has been reported to have played an important part in the formation of cassiterite-bearing veins containing zinnwaldite, and cassiterite-bearing (lithium) pegmatites which carry lepidolite, spodumene and other lithium minerals.

The theory that sodium and possibly other alkali stannates are responsible for the transport of tin in hydrothermal solutions has been supported by various other workers - notably V.L. Barsukov 1953, 1957 and 1958, and V.G. Tronev 1946. Barsukov 1966, has however shown experimentally that in the formation of deposits of quartz-cassiterite type the most probable form of tin transport is as a hydroxofluor-stannate complex of tin of the $(SnF_x(OH)_{6-x})^{2-}$ type. Possible compounds suggested include:-

$$K_2(SnF_x(OH)_{6-x})$$

$$Na_2(SnF_x(OH)_{6-x})$$

He has proved experimentally that fluorine plays an essential role in the formation of suitable complexes for the transport of tin. The suggestion that fluorine is also involved in the transport of tin made it necessary to search for fluorine in the hydrothermal deposits of Ankole.

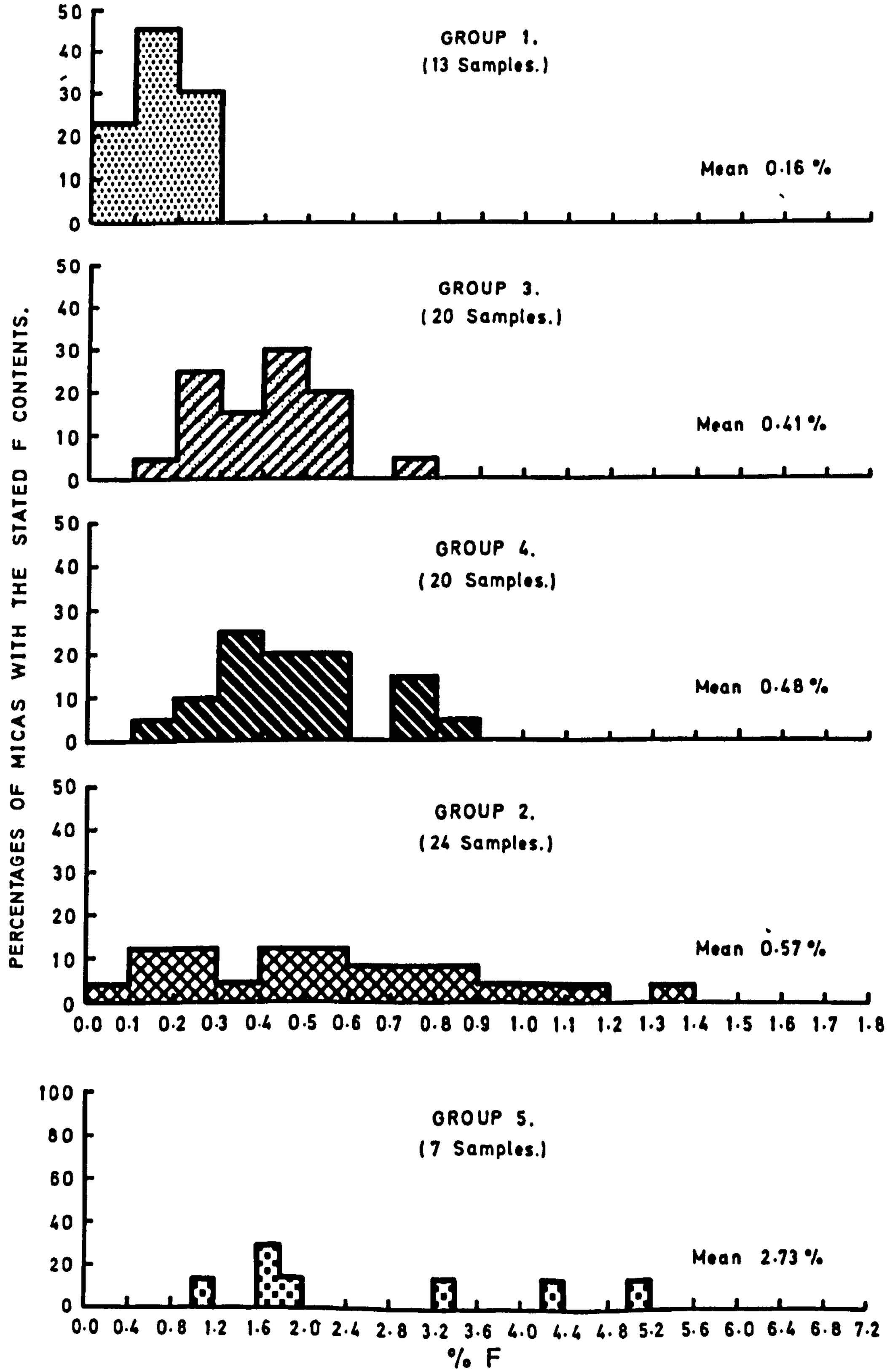
Fluorine-bearing minerals such as fluorite and topaz have not so far been found in hydrothermal tin deposits in Ankole, but muscovite, which can accomodate considerable amounts of fluorine in the lattice, occurs in abundance. It was therefore decided to analyse all the muscovite obtained from the hydrothermal deposits for fluorine to determine whether they contain sufficient fluorine to account for the transport of tin. At the same time muscovites from the other deposit types were also analysed for Fluorine to enable comparisons with the muscovite from the hydrothermal tin deposits to be made.

The fluorine contents of the muscovites were determined using the colorimetric method of Huang and Johns (1966), and the results appear in table 23, (see appendix). Histograms were again plotted to show the distribution of fluorine in the different muscovite groups (see fig.34).

The histograms show that the muscovites from the hydrothermal veins

FIG 34

DISTRIBUTION OF F IN MICAS.



contain 0.1 - 0.9% fluorine which is more than enough to account for the transport of all the tin found in the hydrothermal deposits. The mean fluorine content of the muscovites from the hydrothermal veins is 0.48% which is very similar to that obtained (0.52%F) for muscovites from all the mineral deposits taken as a whole.

The average fluorine contents of the muscovites from the hydrothermal quartz cassiterite veins and the mineral deposits as a whole are slightly below the average (0.6%) fluorine content of natural muscovite quoted in Deer, Howie and Zussman, 1962, Vol.3, p.14.

The results indicate that although there was probably sufficient fluorine present in the mineralising fluids to form the necessary complexes to transport the tin, no outstanding concentration of fluorine occurred during formation of the hydrothermal quartz-cassiterite-bearing veins.

Only the lithian muscovites and a small proportion of late-formed muscovites from the granite pegmatites have been found to contain markedly high concentrations of fluorine (1-5%F). The high fluorine content of these late-formed muscovites is however easy to explain as strong concentration of fluorine often occurs during the final stages of pegmatite crystallisation.

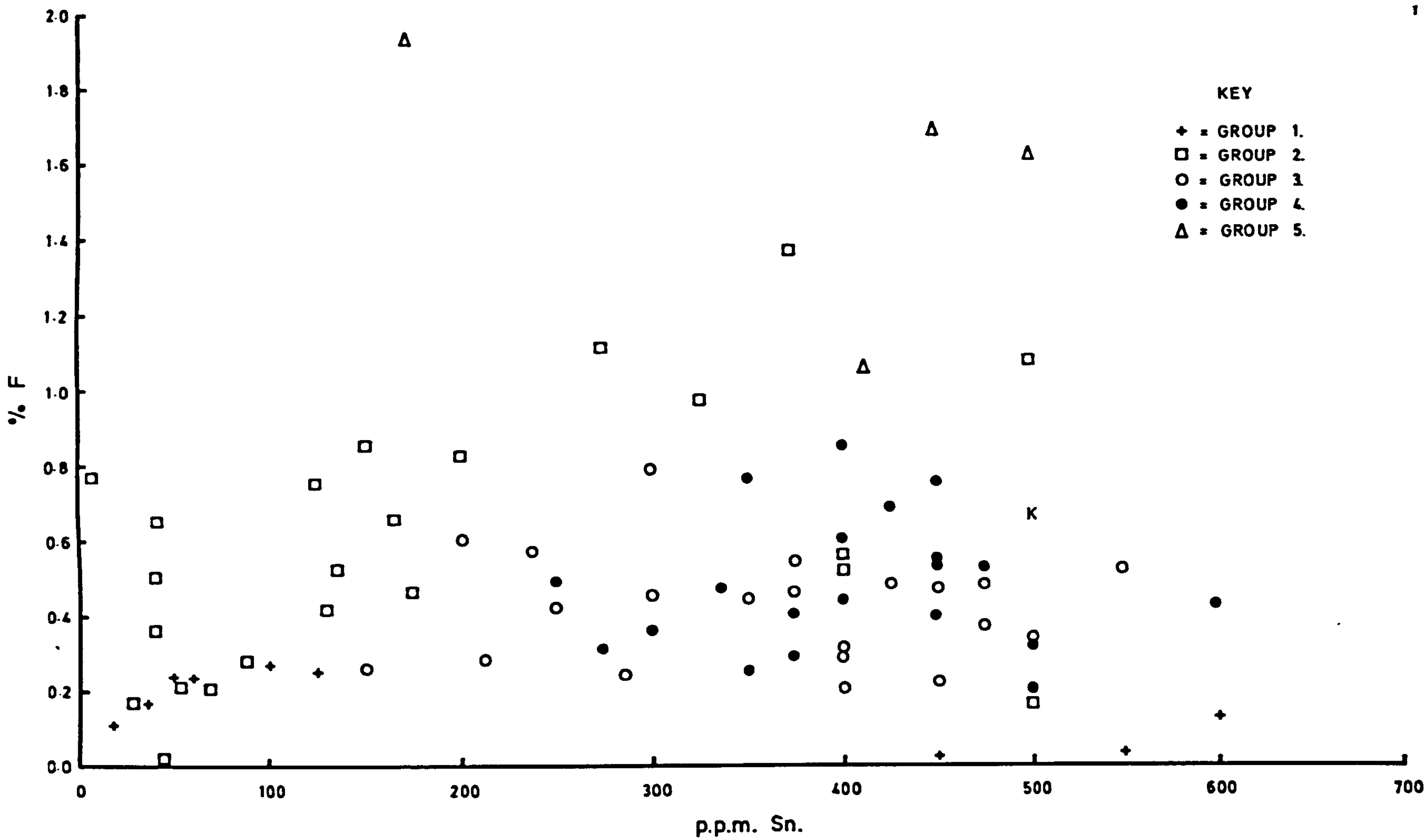
Relationship between tin and fluorine in the muscovites

A diagram has also been plotted (fig. 35) to see whether there is any direct relationship between the tin and fluorine contents of the muscovite from the different deposit types.

In most cases no direct relationship emerges, but some muscovites and lithian muscovites from the granite pegmatites tend to show an increase in tin content with increasing fluorine content. This suggests that in the case of the granite pegmatites, fluorine played an important role in the

FIG 35

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN F AND Sn IN MICAS.



transport of tin.

The absence of a direct correlation between tin and fluorine in muscovites from the hydrothermal quartz veins (and quartz-mica veins) does however not rule out the possibility that flourine also played an important role in the transport of tin during the formation of these deposits. As has already been pointed out, the muscovites form the hydrothermal quartz veins and quartz mica veins contain more than sufficient flourine to account for the transport of all the tin now present in these deposits.

Summary

The geochemical investigations into the composition of muscovites from the hydrothermal tin veins have shown that the muscovites contain all the elements necessary for the formation of the complexes which were involved in the transport of tin.

The relatively high concentrations of sodium in the muscovites from the hydrothermal tin deposits and the constant association of cassiterite with albite in the pegmatites and pegmatitic granites, suggests that the complex $Na_2(SnF_x(OH)_{6-x})$ may have been the major carrier of tin in the hydrothermal deposits of S.W. Ankole.

CHAPTER IX

THE GEOCHEMISTRY OF TIN IN MICAS FROM THE MINERAL DEPOSITS AND PEGMATITIC GRANITES OF S.W. ANKOLE

The Geochemistry of Tin in Micas from the Mineral Deposits and Pegmatitic Granites of S.W. Ankole

Various workers have studied the tin content of micas from tin bearing and non-tin bearing deposits in other parts of the world and have reported the ranges of tin concentrations present. (Borovic, S.A. 1937, Oftedahl, I. 1940, Ahrens, L.H. and Liebenberg, W.R. 1950, Jedwab, J. 1953, Hoffman, V. and Trdlicha, Z. 1963, and Popolitov, E.I. 1964).

L.H. Ahrens working on muscovites and lepidolites and V. Hoffman working on zinnwaldites have also reported that only a small proportion of the tin found in the micas is bound to the lattice and that the remainder occurs as minute inclusions of cassiterite.

A comparative study has therefore been made of the tin content of muscovites (including lithian muscovites) from the mineral deposits and pegmatitic granites in S.W. Ankole, and an attempt has been made to determine the form in which the tin occurs in them.

82 samples of muscovite were analysed colorimetrically for tin using a method devised by the writer (see appendix p. 227), by which both the total tin content and the tin content excluding cassiterite, can be determined. The total tin content of the samples was determined by using a method of sample attack that dissolves the mica <u>and</u> any cassiterite inclusions present. The tin content excluding cassiterite - which has been called the 'acid soluble' tin content - was determined by using a method of sample attack that dissolves only the mica, liberating lattice or absorbed tin. Any cassiterite present remains undissolved.

Results

The "total" and "acid soluble" tin contents of the muscovite analysed and the differences between the two values (i.e. cassiterite contents) are presented in table 44, in which the samples have been divided into the same groups as were used for comparison of alkali contents. The total and acid soluble tin contents of the muscovite from each of the groups have also been plotted on histograms to enable comparisons to be made (see figs. 36-37).

Examination of the table 44 shows that there is a difference between the total and acid soluble tin contents of quite a large number of the samples analysed. In a few cases where the difference is large, (50-200 ppm.), there can be no doubt that the samples contain small quantities of cassiterite.

A substantial proportion of the muscovite containing large differences between total and soluble tin content either come from hydrothermal quartz-cassiterite bearing veins or have been separated from material from quartz-mica veins or mica rock units in pegmatites which may contain some free cassiterite, (Groups 3, 4, 5, on histograms). The cassiterite in the samples may be present as minute inclusions (as suggested by L.H. Ahrens and W.R. Liebenberg 1950) or may have been derived by contamination from macroscopic fragments of cassiterite originally present in the samples before preparation for analysis.

The samples containing only small differences between total and soluble tin content (up to 25 ppm), probably do not contain cassiterite and allowances of this magnitude must be made for possible experimental error in the method of analysis (over the range 100-600 ppm Sn).

The results show that a small proportion of the samples analysed contain cassiterite, but that in the majority of cases the tin must be present in some other form.

FIG 36

DISTRIBUTION OF TOTAL Sn IN MICAS.

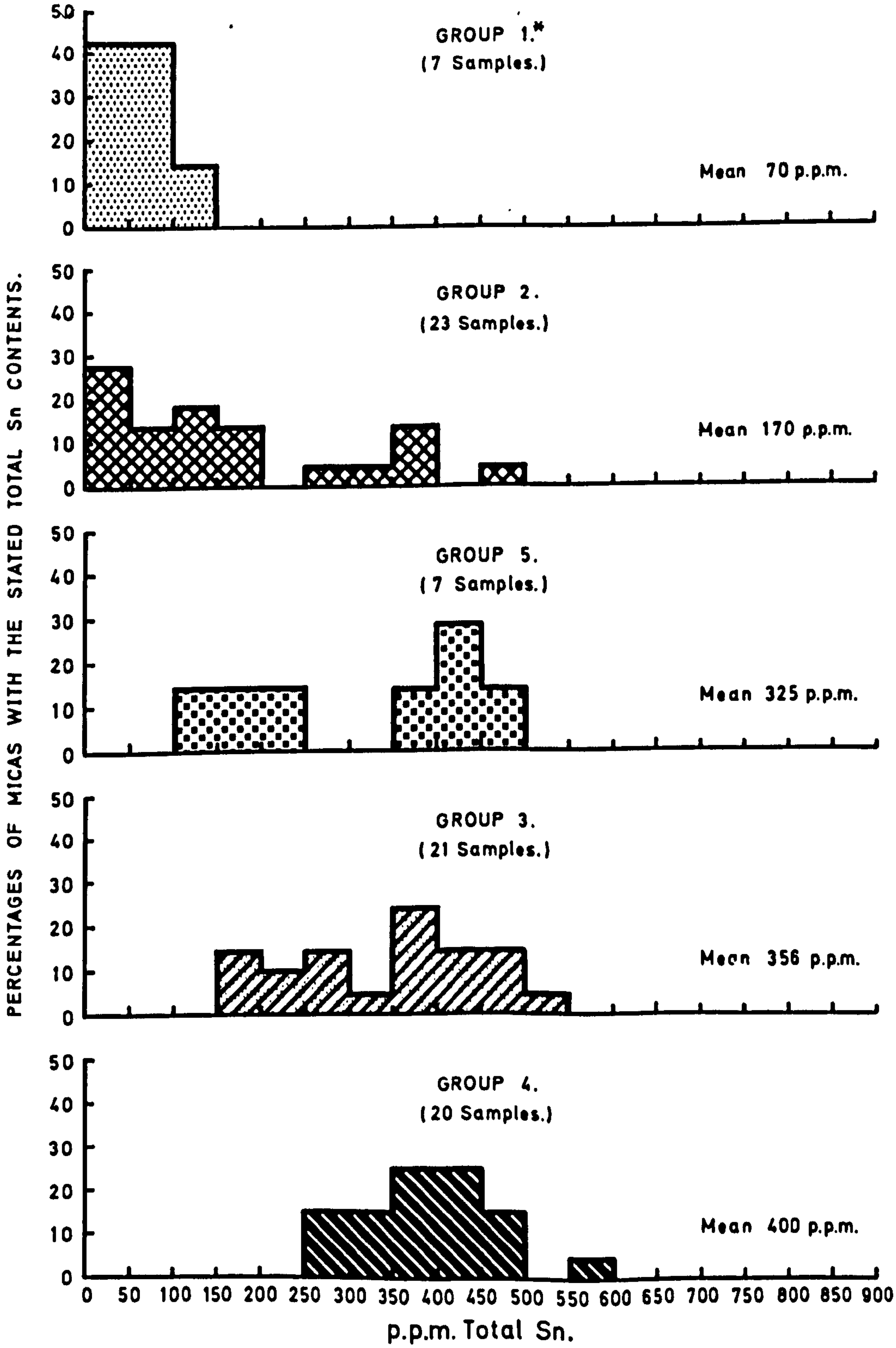
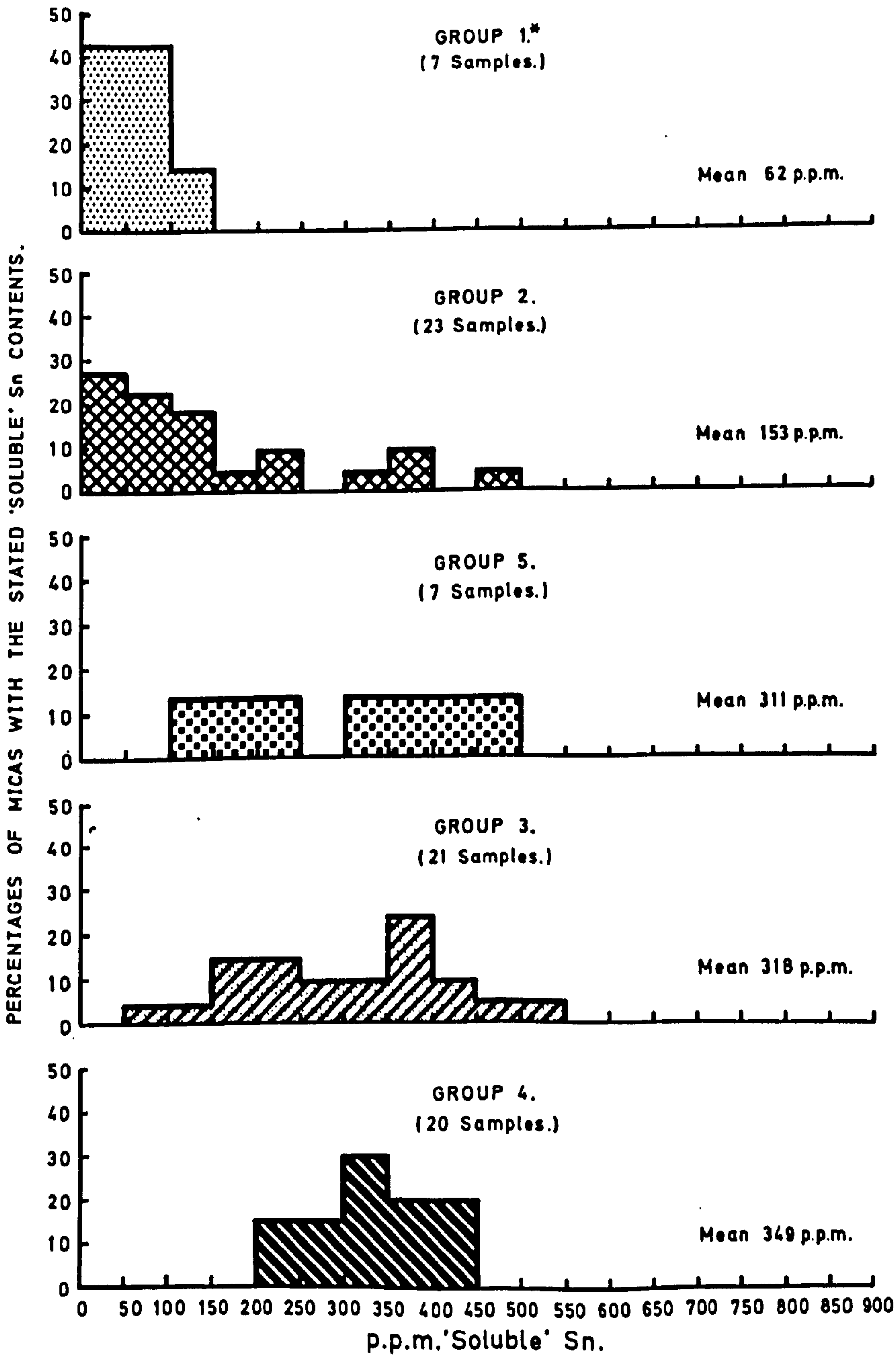


FIG 37

DISTRIBUTION OF 'SOLUBLE' Sn IN MICAS.



The possibility that substitution of tin can occur in the muscovite lattice has been recognised for a long time, and suggestions have been made (V. Hoffman 1963) that up to 300 ppm. of Sn can replace Fe in the zinnwaldite lattice.

The writer has found that up to 550 ppm. of tin excluding cassiterite can occur in the muscovites and that this is released when the samples are decomposed using a mixture of concentrated hydrofluoric and sulphuric acids. It is possible that the tin liberated by complete solution could be contained in the lattice, but the idea occurred to the writer that the tin may also be present as an acid soluble compound which is either absorbed onto or included within the muscovite.

In order to test this hypothesis finely powdered samples of muscovite were treated with concentrated hydrochloric acid or aqua-regia to determine whether preferential solution of included tin would occur (see footnote).

Method

Finely powdered 1 gram samples of muscovite (M34) known to contain 550 ppm of tin (excluding cassiterite) were leached with concentrated hydrochloric acid or aqua-regia for 1 hour at 100°C, and the resulting solutions

---

Footnote: If lattice tin only is present in a muscovite undergoing partial solution, then the percentage of tin released by partial solution should be proportional to the percentage of muscovite dissolved i.e., the ratio of the percentage of tin released to the percentage of muscovite dissolved should be 1:1. If tin is also present in the form of an acid soluble compound (which is absorbed onto or included within the muscovite), then the ratio of the percentage of tin released to the percentage of muscovite dissolved should be greater than 1:1.

were filtered off and analysed for tin. The muscovite residues remaining after leaching with acid were washed, dried, and weighed to determine the weight loss due to partial solution.

Results (see table 37)

120 ppm. of tin were released from the sample treated with concentrated hydrochloric acid with an attendant weight loss of 0.117 grams and 110 ppm of tin were released from the sample leached with aqua-regia with an attendant weight loss of 0.115 grams. This represents a 22% loss in tin content for an 11.8% loss in weight for the muscovite treated with concentrated hydrochloric acid, and a 20% loss in tin content for an 11% loss in weight for the sample treated with aqua-regia.

Conclusions

The results show that the ratio of the percentage of tin released, to the percentage of muscovite dissolved is approximately 2:1 which is greater than that which would have occurred if the tin had only been present in the lattice.

It is therefore suggested that in the samples tested, a proportion of the tin present is in the form of an acid soluble compound.

One fairly well known naturally occurring compound of tin which is soluble in concentrated hydrochloric acid or aqua-regia, is the hydrated stannic oxide varlamoffite (originally described by N. Varlamoff 1948, from tin deposits in the Belgian Congo. Re: also A. Russell and E.A. Vincent 1952).

Although varlamoffite has so far only been described as a secondary mineral produced by supergene alteration of stannite or cassiterite in tin deposits, the writer sees no reason why varlamoffite should not occur in small quantities in micas which have formed in a tin-rich environment.

Table 37. Results of solubility tests on tin bearing muscovite

Sample No.	Wt. of Muscovite Sample	Loss in wt. due to partial soln.* of sample	% loss in wt.	Original Sn content of muscovite sample	Sn loss due to partial soln. of sample	% loss in Sn content	Ratio of % Sn loss to % Wt. loss
M34	1.000 g.	<u>Hydrochloric acid</u> 0.117 g.	22.0	550 ppm.	120 ppm.	11.8	2:1
M34	1.000 g.	<u>Aqua-regia</u> 0.115 g.	20.0	550 ppm.	110 ppm.	11.0	2:1

* Samples leached for 1 hour at 100°C in Conc. HCl or Aqua-regia

It is therefore proposed that a portion of the trace tin which occurs in the muscovites analysed may be in the form of the hydrated stannic oxide varlamoffite. This compound may occur either in the form of tiny inclusions or adsorbed as a uniform layer on the cleavage surfaces of the muscovites.

CHAPTER X

THE BEHAVIOUR AND DISTRIBUTION OF ALKALIS AND FLUORINE IN MICAS FROM THE MINERAL DEPOSITS AND PEGMATITIC GRANITES

The behaviour and distribution of Alkalis and Fluorine in Micas from the Mineral deposits and pegmatitic granites of S.W. Ankole

The possible isomorpous replacements involving alkalis and fluorine which can occur in muscovites are as follows:- (Deer, Howie and Zussman 1962).

For K - Na, Rb, and Cs

For Octahedral Al, - Li

For (OH) - F

In order to determine whether the effects of isomorphous replacements between the alkalis can be observed in the muscovite from the mineral deposits and pegmatitic granites of S.W. Ankole, diagrams have been drawn plotting: K_2O against Na_2O, $Rb_2O + Cs_2O$, $Na_2O + Rb_2O + Cs_2O$, and Rb_2O against Cs_2O (figs. 38 - 42).

1. K_2O v Na_2O

Fig. 38 shows a plot of the K_2O v Na_2O contents of the muscovites from all the deposit types (fig.38 and all the other diagrams include lithian muscovites). Fig. 38 shows that as the potash (K_2O) content of the muscovites decreases the Na_2O content increases and that progressive replacement of K^+ by Na^+ clearly occurs.

2. K_2O v $Rb_2O + Cs_2O$

The diagram in which percentage $Rb_2O + Cs_2O$ have been plotted against K_2O (fig. 39) shows no such clear relationship and the lack of any trend may reflect the fact Rb^+ and Cs^+ (being rare alkalis) are not always available to substitute to the maximum possible degree. It is also possible that sodium when present in sufficient quantity will enter the muscovites preferentially to the other two alkalis. Some sort of relationship between the entry of sodium and rubidium into the muscovite can be

KEY TO DIAGRAMS SHOWING RELATIONSHIPS OF ELEMENTS IN MICAS

Group 1.	Muscovites from pegmatitic granites
Group 2.	Muscovites from granite pegmatites (excluding late mica-rock or 'greisen' units).
Group 3.	Muscovites from quartz-mica veins and 'greisen' or mica-rock units in pegmatites.
Group 4.	Muscovites from hydrothermal quartz-cassiterite-bearing veins.
Group 5.	Lithian muscovites from pegmatites.

FIG 38

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN Na_2O AND K_2O IN MICAS.

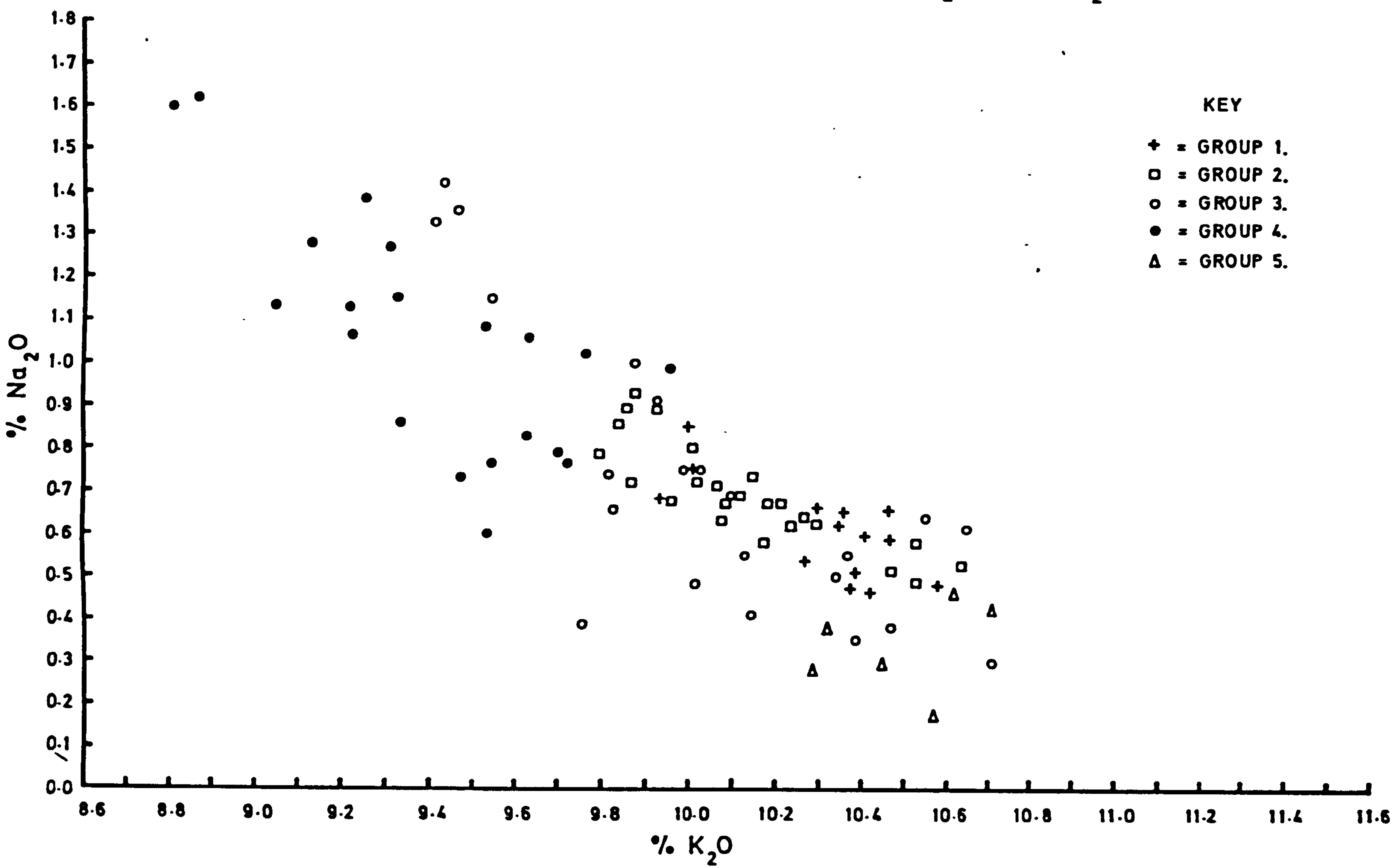
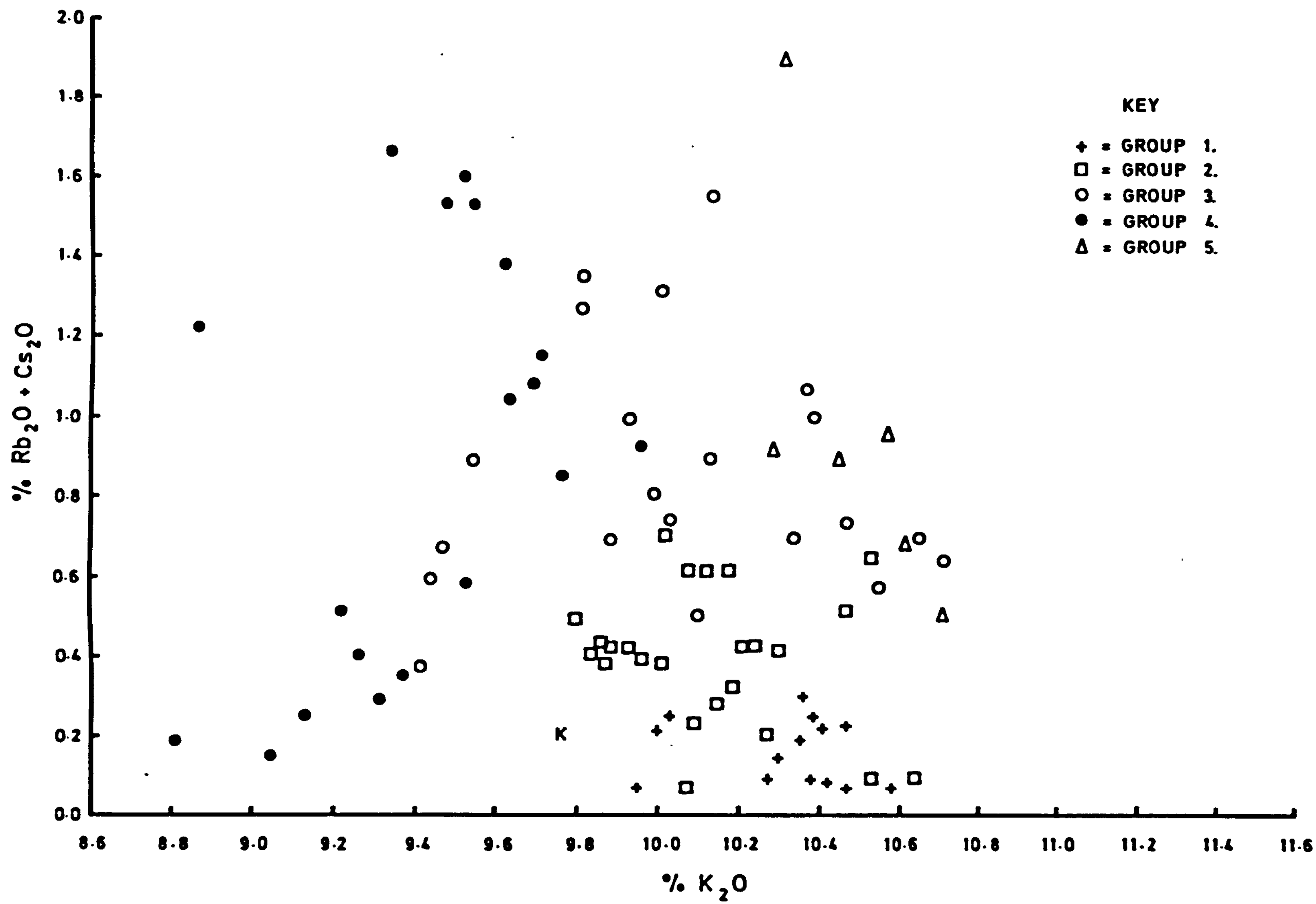


FIG 39

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN $Rb_2O + Cs_2O$ AND K_2O IN MICAS.



observed if the Na_2O contents of muscovite from the hydrothermal veins are plotted against the Rb_2O contents (fig. 40). It will be seen from fig. 40 that the muscovite containing the highest Na_2O values contain the lowest Rb_2O values and vice-versa. This relationship has not however been observed in muscovite from other mineral deposit types.

3. K_2O v $Na_2O + Rb_2O + Cs_2O$

Fig. 41 in which percentage K_2O has been plotted against total percentage $Na_2O + Rb_2O + Cs_2O$ shows that as the K_2O content of the muscovite decreases the content of the other alkalis increases and that progressive replacement of K_2O by $Na_2O + Rb_2O + Cs_2O$ occurs. The scatter of points on the diagram is much greater than that obtained on the diagram for K_2O v Na_2O as there is not such a simple relationship involved.

4. Rb_2O v Cs_2O

A diagram has also been drawn to determine whether there is any relationship between the rubidium and caesium contents of the muscovites (fig. 42). The result shows (see fig. 42) that these two elements tend to be concentrated together and that samples containing high rubidium also contain high caesium.

The diagram (fig. 42) also shows that a number of muscovites (14) have been found which contain relatively high concentrations of Rb_2O ($>$ 0.90%) or Cs_2O ($>$ 0.15%). The muscovites which contain the highest concentrations of Rb_2O i.e.: 1.34-1.42% (M65, 66, 67 and 68), are from hydrothermal quartz-cassiterite-bearing veins at Nyamaherere, whereas the muscovites which contain the highest concentrations of Cs_2O i.e.: 0.25-0.36% are from mica rock units in granite pegmatites (M28, 29 and 30 - Kazumo, M34 - Bitaka and M72 - Kitofa).

FIG 40

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN Na_2O AND Rb_2O IN MICAS FROM HYDROTHERMAL TIN DEPOSITS.

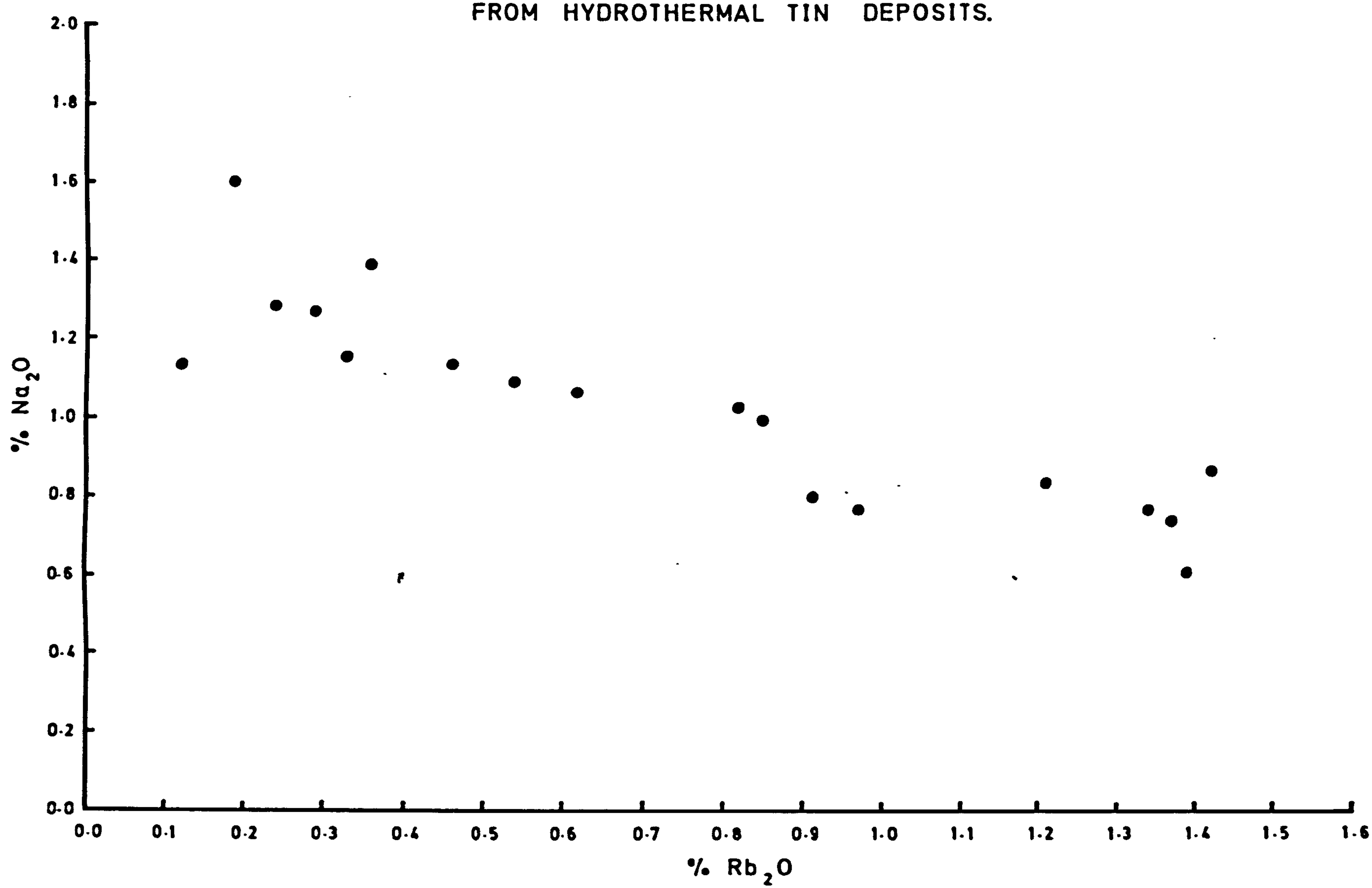


FIG 41

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN $Na_2O + Rb_2O + Cs_2O$ AND K_2O IN MICAS.

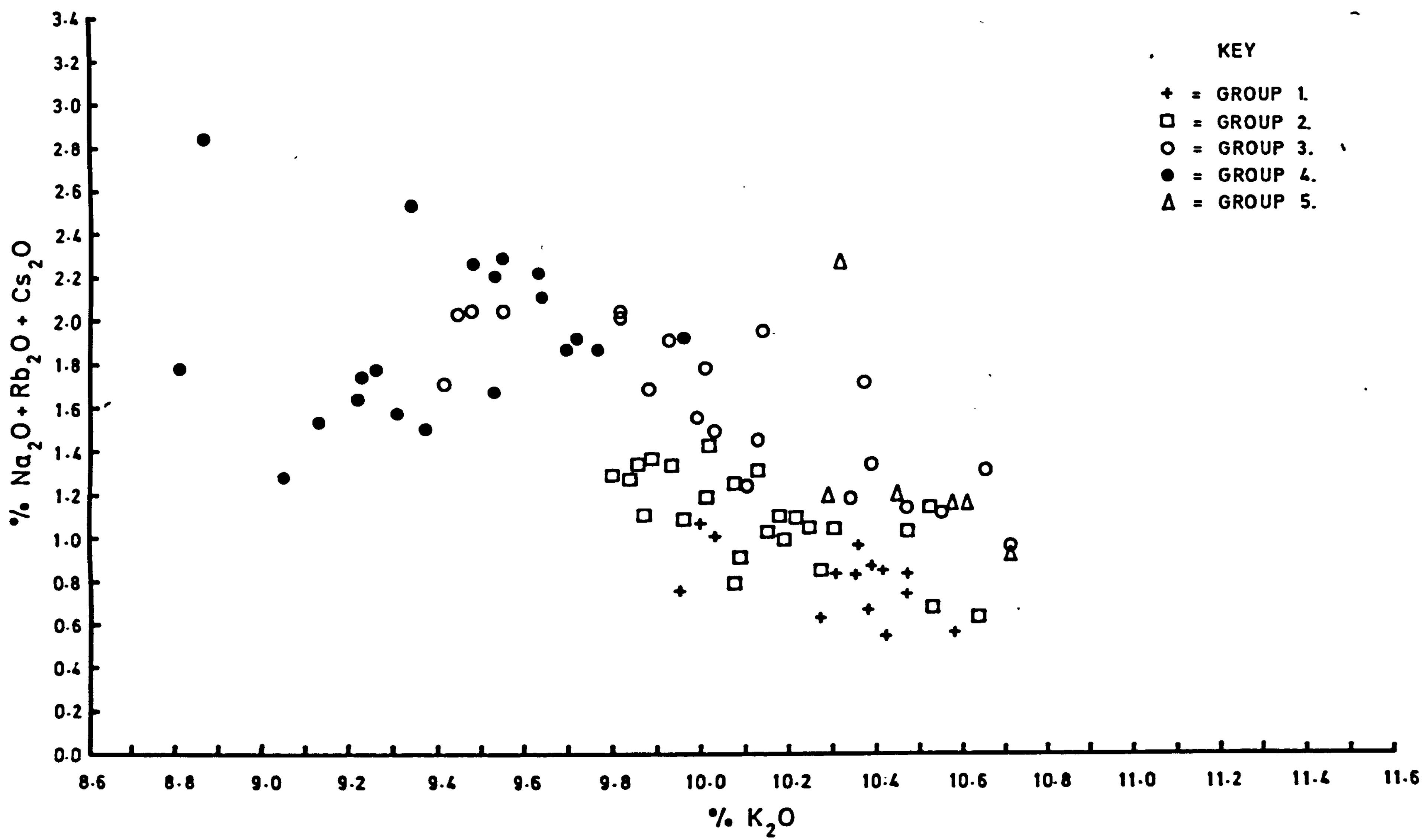
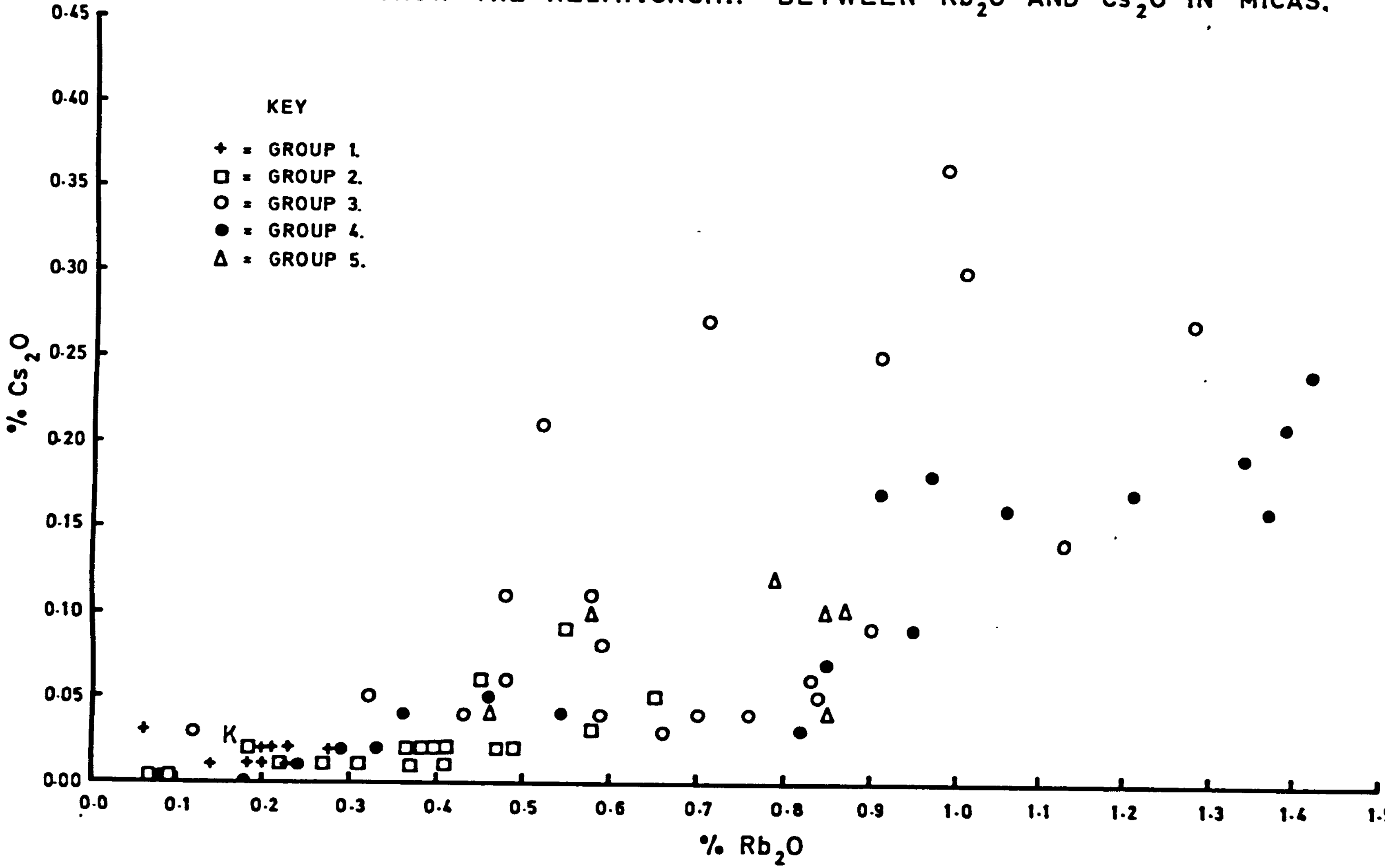


FIG 42

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN Rb_2O AND Cs_2O IN MICAS.



The occurrence of high rubidium and caesium in the muscovites (particularly 1.42% Rb_2O in M65 from Nyamaherere and 0.36% Cs_2O in M72 from Kitofa) is interesting as such high concentrations of the rare alkalis are usually only found to occur in lithian muscovites and lepidolites.

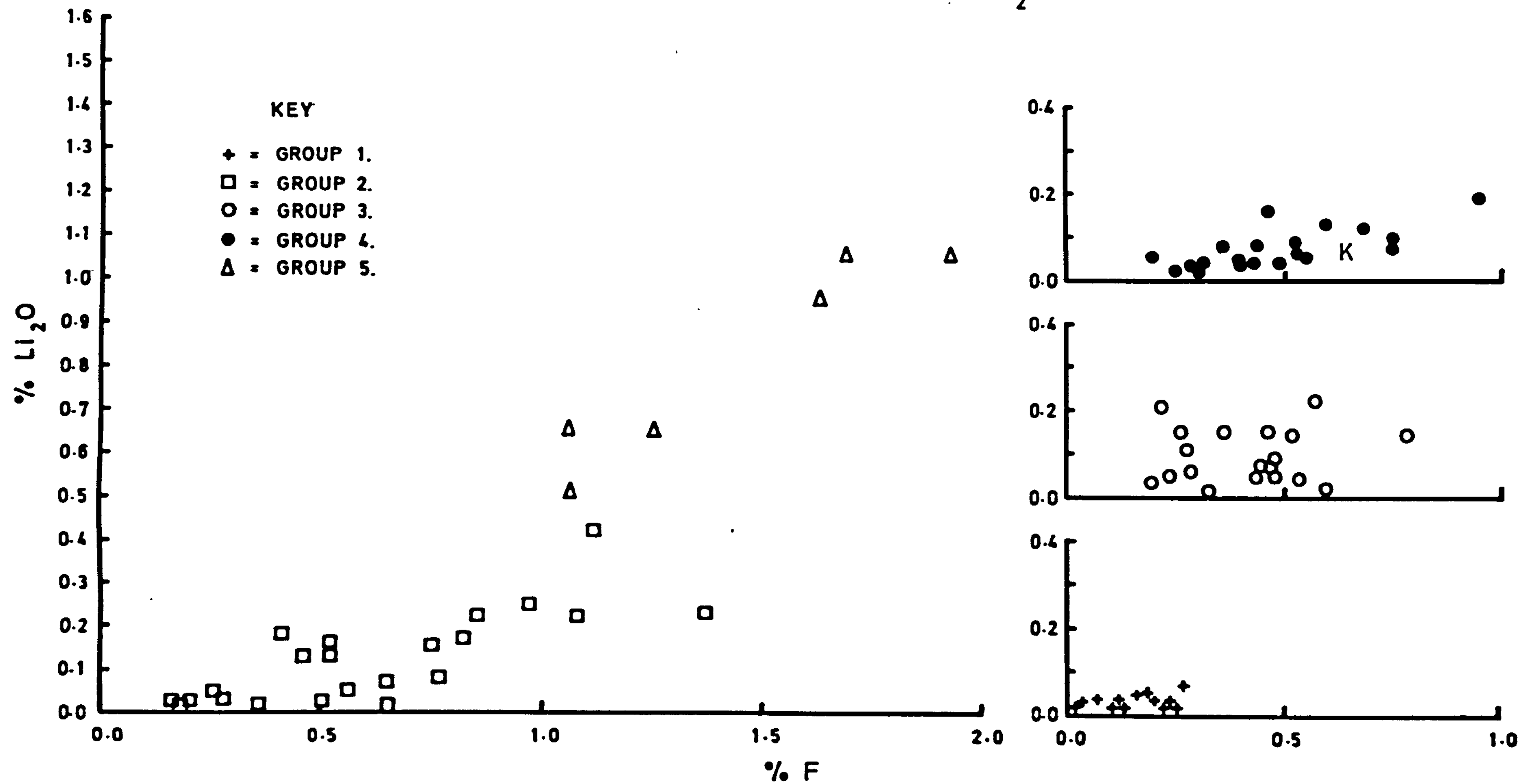
The above figures show that in S.W. Ankole strong concentration of the rubidium and/or caesium must have occurred during the formation of muscovite in some of the hydrothermal quartz cassiterite-bearing veins and pegmatite mica rock units.

Relationship between lithium and fluorine

An interesting correlation has been found to occur between lithium and fluorine in the muscovites analysed. If the lithium and fluorine contents of the muscovites from the different mineral deposits are plotted on a diagram (fig. 43) it can be seen that the muscovites containing high lithium also contain high fluorine. This has been found to apply particularly to the lithian muscovites from the granite pegmatites and suggests that lithium and fluorine are concentrated together in pegmatite forming processes.

FIG 43

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN Li_2O AND F IN MICAS.



CHAPTER XI

INVESTIGATIONS INTO THE POSSIBILITIES OF USING MUSCOVITE AS AN INDICATOR IN PROSPECTING FOR TIN DEPOSITS IN S.W. ANKOLE

Investigations into the possibilities of using Muscovite as an Indicator in prospecting for Tin Deposits in S.W. Ankole

In the past suggestions have been made (L.H. Ahrens, 1950) that the tin content of muscovites can be used as a guide in prospecting for tin deposits. Examination of the results for total and acid soluble tin in micas from the various mineral deposits in S.W. Ankole (see figs.36 & 37) shows that there is insufficient difference in tin content between muscovites from the hydrothermal quartz-cassiterite veins and those from other deposit types to enable tin content alone to be used as a prospecting guide. For example muscovites containing 250-500 ppm. of tin have been obtained from several pegmatites which are completely barren of cassiterite, and many of the samples in group 4 which contain high tin values have also been obtained from non cassiterite-bearing deposits.

The muscovites from the hydrothermal tin veins (group 5) have however all been found to contain at least 250 ppm of Sn and this may be useful in prospecting, in that any muscovites found to contain less than 250 ppm can be ignored, when searching for hydrothermal tin deposits.

It is, however, possible to use the muscovites as specific prospecting guides in searching for hydrothermal tin deposits if the alkali content as well as tin content is taken into consideration. It has been shown (see p.125) that muscovites from the hydrothermal deposits contain higher Na_2O and combined $Na_2O + Rb_2O + Cs_2O$ contents and lower K_2O contents than many of the muscovites from the other deposit types. If diagrams are drawn plotting the percentage Na_2O, K_2O or combined $Na_2O + Rb_2O +$ Cs_2O of the muscovites against tin content in ppm. for samples from each of the five groups (representing samples from each group by a different symbol), then it will be seen that the muscovites from the hydrothermal tin deposits fall into definite fields on the diagrams (outlined by rectangles - see figs. 44 - 46).

In fig. 44 all the muscovites from the hydrothermal veins lie above 0.7% Na_2O and 250 ppm Sn; in fig. 45 , the muscovites all lie below 9.8% K_2O and above 250 ppm Sn and in fig. 46 , the muscovites all lie above 1.4% Na_2O + Rb_2O + Cs_2O and 250 ppm Sn. The only significant number of muscovites from other deposit types which overlap the fields occupied by muscovites from the hydrothermal veins are muscovites from group 4. If the number of muscovites from the hydrothermal deposits and other deposit types present in the fields in each of the diagrams are counted and totalled, then the percentage of the total number of samples represented by hydrothermal deposits can be calculated in each case (66% in fig. 44 , 83% in fig. 45 , and 59% in fig. 46). It will be apparent that fig. 45 (in which percentage K_2O has been plotted against Sn content in ppm) provides the best separation of muscovites from the hydrothermal tin deposits, and that 83% of the muscovites lying in the field $<$ 9.8% K_2O and $>$ 250 ppm. Sn are from hydrothermal quartz cassiterite veins.

The potash versus tin contents of muscovites can therefore be used as almost specific prospecting indicators for hydrothermal tin deposits in S.W. Ankole. The Na_2O v Sn, and Na_2O + Rb_2O + Cs_2O v Sn contents can also be used but do not distinguish the hydrothermal deposits from the other deposit types so clearly. It has also been found that it is possible to distinguish muscovite from hydrothermal deposits from those from other deposits, on alkali content alone, if suitable diagrams are plotted.

Figs. 47 & 48 show plots of percentage Na_2O against percentage K_2O,

FIG 44

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN Na_2O AND Sn IN MICAS.

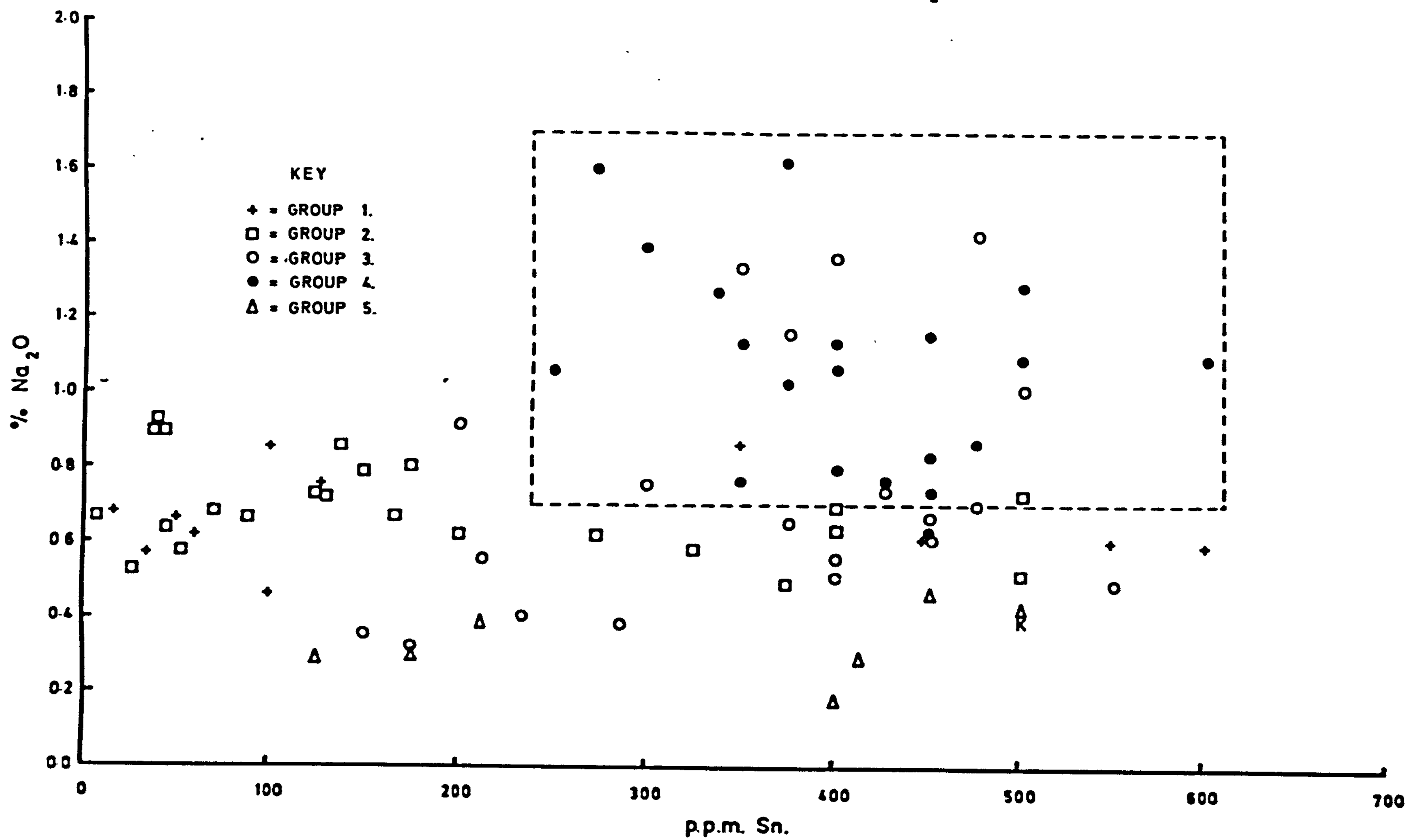


FIG 45

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN K_2O AND Sn IN MICAS.

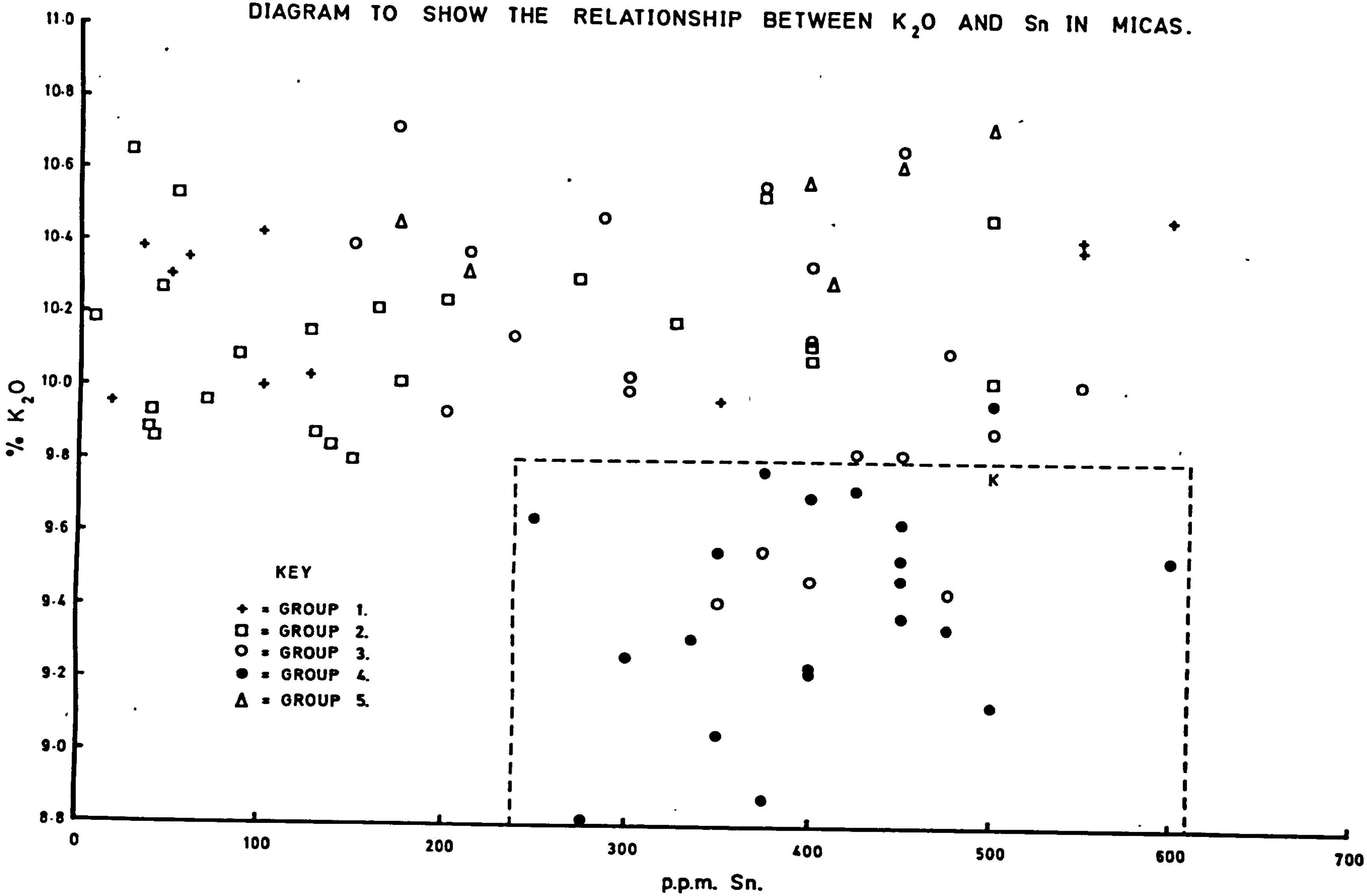
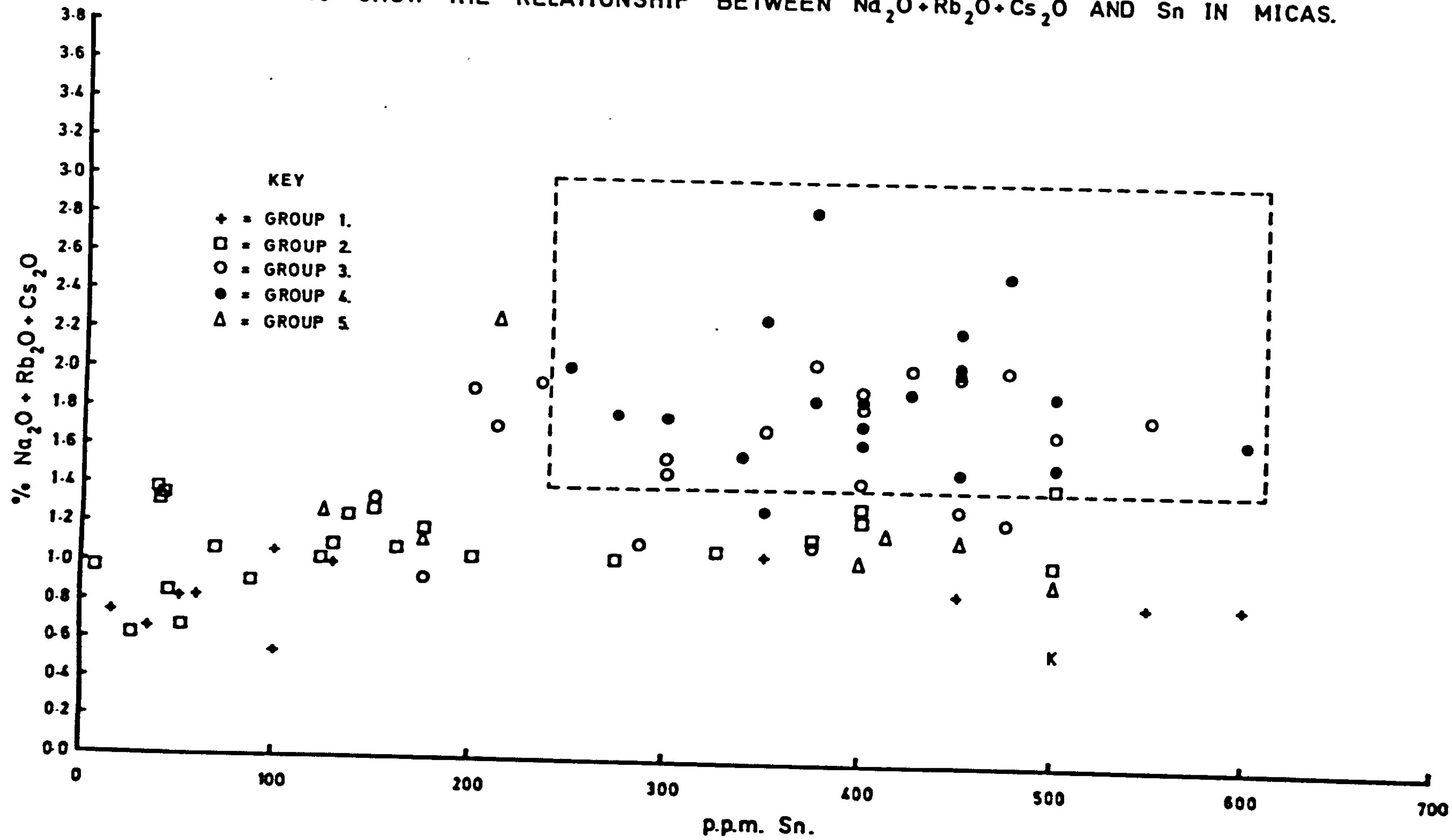


FIG 46

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN $Na_2O + Rb_2O + Cs_2O$ AND Sn IN MICAS.



and percentage combined $Na_2O + Rb_2O + Cs_2O$ against pcercentage K_2O for muscovites from the 5 main groups. The muscovites from the hydrothermal tin deposits all lie in a separate portion of both diagrams and only a few muscovites from other deposit types (group 4 only) occur among them. The diagrams show that muscovites containing 8.8 - 9.8% K_2O and 0.5 - 1.7% Na_2O or 8.8 - 9.8% K_2O and 1.2 - 3.0% $Na_2O + Rb_2O + Cs_2O$, are almost specific indicators of hydrothermal tin deposits.

Conclusions

Geochemical parameters have been obtained by means of which it is possible to distinguish muscovites from the hydrothermal tin deposits of S.W. Ankole from those of any other deposit type.

The parameters enable muscovite to be used as an indicator in prospecting for tin deposits in S.W. Ankole.

There is however one important point which must be made. The results obtained may only be directly applicable in prospecting for new hydrothermal tin deposits within the area already studied. It is possible that the hydrothermal tin deposits in some of the adjacent areas (i.e. Karagwe Tinfields) may contain micas of different compositions.

This is hinted at by the occurrence of 1 muscovite sample from the Kikagati Tin Mine which is different in alkali content from all the other muscovites collected from the hydrothermal tin deposits in S.W. Ankole. The sample lies outside the fields containing the remainder of the muscovites from the hydrothermal tin deposits on most of the diagrams (see figs. 39,44,46,47,48.). (The Kikagati sample is marked"K"). The only diagrams in which the muscovite shows similarities to those from the other deposits are figs. 42 , 43,45(for alkalis). The Kikagati deposit lies in the North part of the Karagwe

FIG 47

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN Na_2O AND K_2O IN MICAS.

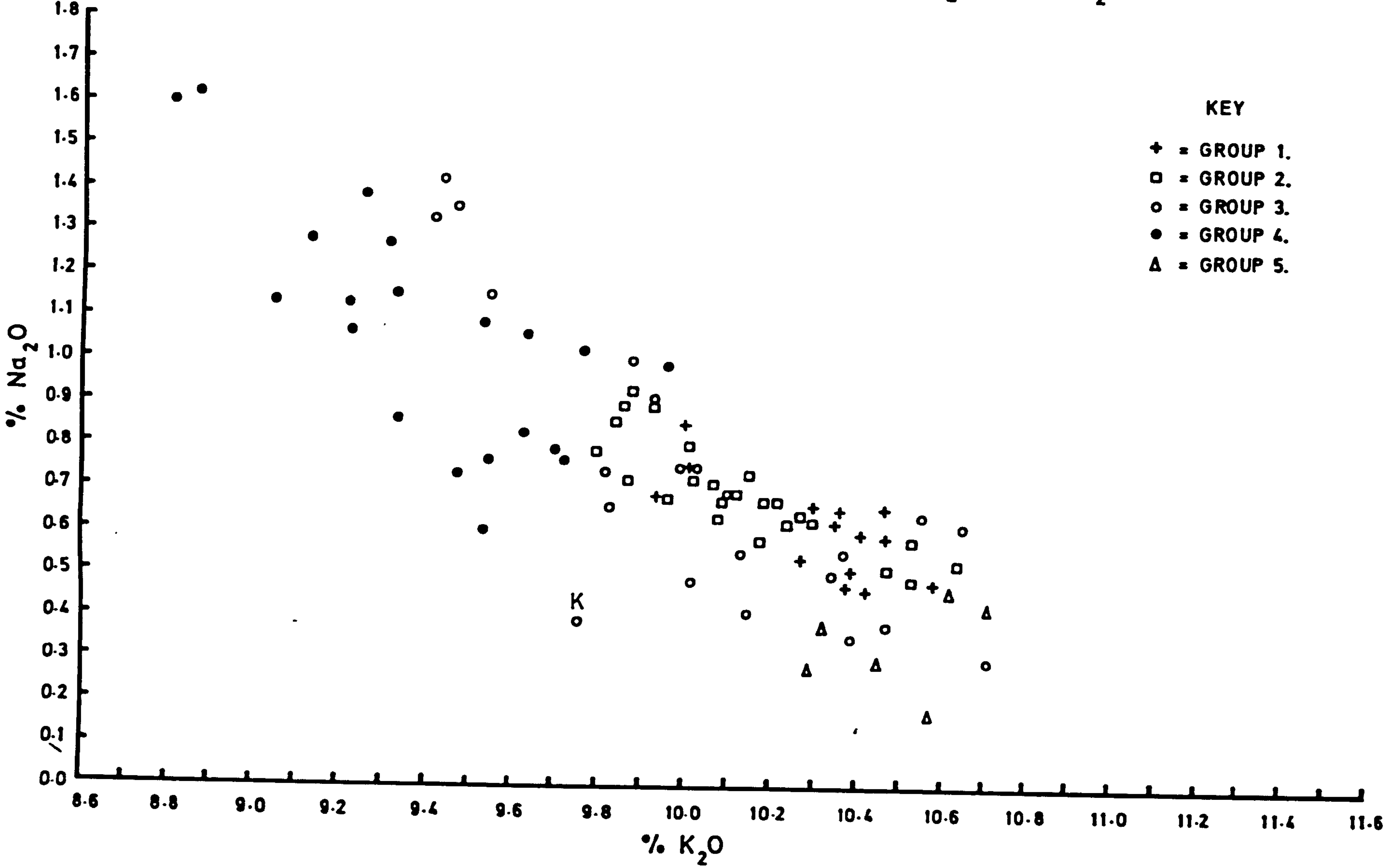
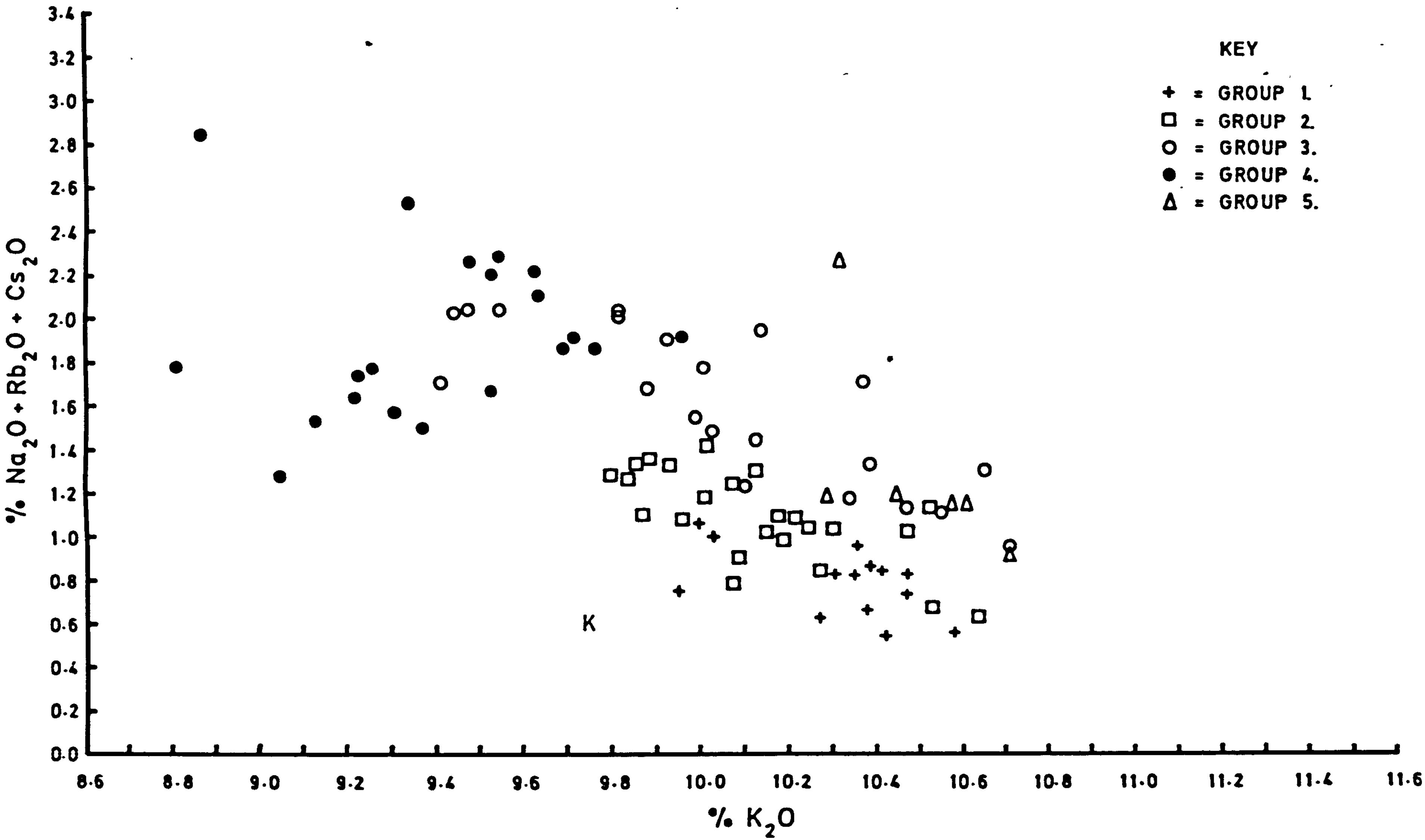


FIG 48

DIAGRAM TO SHOW THE RELATIONSHIP BETWEEN $Na_2O + Rb_2O + Cs_2O$ AND K_2O IN MICAS.



Tinfield and the low Na_2O and total Na_2O + Rb_2O and Cs_2O content of the muscovite may indicate that the Kikagati tin deposit has formed under slightly different geochemical conditions to those found elsewhere in Ankole.

CHAPTER XII

SUMMARY OF THESIS

SUMMARY

1. Geology of the Tin and Beryllium Mineralisation

Widespread tin and beryllium mineralisation has affected S.W. Ankole and is represented by the occurrence of granite pegmatites, quartz-mica cassiterite-bearing veins and hydrothermal quartz cassiterite-bearing veins.

The mineralised area is one of several tin and beryllium bearing metallogenic provinces which occur along the Kibaran orogenic belt and the mineral deposits contained therein were formed as a result of post-tectonic magmatic activity at the end of the Kibaran orogeny (800 - 1000 m.y. ago).

The mineral deposits of S.W. Ankole occur in the exo- and endocontact zones of updomed pre- syn- and late-tectonic 'arena' granites which were emplaced into metasediments of the Karagwe-Ankolean System during the Kibaran orogeny, and the mineralisation, which post-dates emplacement of the granitic rocks, shows a marked regional zoning with respect to the granite boundaries.

The beryl-bearing granite pegmatites show a close association with sporadic developments of post-tectonic intrusive quartz-microcline-muscovite pegmatitic granites which occur in marginal and inhomogeneous portions of the (older) arena granites and the pegmatites occur both in granite and in metasediments adjacent to granite.

The quartz-mica cassiterite-bearing veins do not show an association with pegmatitic granites but occur in metasediments close to the margins of the arena granites.

The hydrothermal quartz cassiterite-bearing veins are more widespread in their distribution and occur in metasediments both close to and at a

distance from the margins of the arena granites. The quartz-mica and hydrothermal quartz cassiterite-bearing veins occur particularly where Karagwe-Ankolean metasediments lie in sharp, hydrothermally altered contact with the Kibaran granites; i.e. where the contacts have allowed passage of hydrothermal fluids from depth.

The beryl bearing pegmatites are very variable in structure and show large variations in texture, mineralogy, zoning, replacement and alteration, and have been classified into five main groups:

1. Microcline-muscovite pegmatites
2. Albite-muscovite replaced pegmatites
3. Kaolinised spodumene-albite replaced pegmatites
4. Lithian muscovite-albite replaced pegmatites
5. Quartz-mica-kaolin pegmatites

The different groups have been found to show different spatial relationships to the granites and can be interior, marginal or exterior in occurrence. The mineralogy of some of the pegmatites has been found to be affected by distance from the parent granite and the marginal and exterior pegmatites have been found to show the strongest replacement, mineralisation, and hydrothermal alteration.

Formation of the pegmatites is believed to have taken place in two stages; primary crystallisation with development of zones of primary crystallisation under closed system conditions, followed in some cases by replacement (to form replacement zones) and hydrothermal alteration under relatively open system conditions.

Three types of replacement have been recognised and each is characterised by its own mineral assemblage.

Where hydrothermal alteration has occurred the pegmatites are strongly kaolinised and contain additional quantities of muscovite and sericite and influx of hydrothermal fluids under open system conditions must be invoked to explain the formation of these minerals. It is believed that the hydrothermal fluids which altered the pegmatites may be related to those which formed the quartz-mica and the hydrothermal quartz cassiterite-bearing veins.

The quartz mica veins show similarities in structure and mineralogy to both the altered quartz-mica-kaolin granite pegmatites and the hydro-thermal quartz cassiterite-bearing veins, and are intermediate or transitional in character.

The hydrothermal quartz veins which are similar to the quartz-mica veins but contain less muscovite are hypothermal and were formed at lower temperatures than the other deposit types. The granite pegmatites, quartz-mica- and hydrothermal quartz-cassiterite-bearing veins are related and similar in age, although age data suggest that the hydrothermal quartz cassiterite-bearing veins may be a little younger than the other deposit types.

2. Geochemistry of the tin and beryllium mineralisation

Geochemical concentration of tin and beryllium has accompanied the formation of all the mineral deposit types. The granite pegmatites contain the bulk of the beryllium concentrated (mainly in the form of beryl) and the quartz-mica and hydrothermal quartz cassiterite-bearing veins contain the bulk of the tin concentrated (mainly in the form of cassiterite).

Study of the geochemical distribution of tin and beryllium in the rocks of S.W. Ankole has shown that with the exception of the post-tectonic pegmatitic granites and granitic and metasedimentary rocks affected by post-tectonic hydrothermal alteration, the rocks all contain average abundances of tin and beryllium. Only rocks that have been subjected to post-tectonic palingenesis, hydrothermal or metasomatic alteration have been found to contain above average concentrations of tin and beryllium.

Concentration of tin and beryllium occurred as a result of two different but related processes which operated at the end of the Kibaran orogeny. Tin and beryllium were concentrated in pegmatitic granite magma formed as a result of palingenesis of pre-existing granitic rocks (containing average abundances of these elements) at scattered regional centres of dynamothermal activity, and tin and beryllium were also concentrated in hydrothermal fluids formed as a result of similar processes operating on a regional scale at depth, probably in the roots of the Kibaran orogenic belt.

The granite pegmatites which show a close association with the pegmatitic granites were formed from the tin and beryllium bearing pegmatitic granite magmas, and the quartz-mica and the hydrothermal quartz cassiterite-bearing veins were formed from the tin and beryllium-bearing hydrothermal fluids.

Primary epigenetic dispersion patterns for tin and beryllium have been obtained from adjacent to all the mineral deposit types and clearly indicate that these elements were epigenetically introduced as a result of the mineralisation.

Study of the geochemistry of the post-tectonic pegmatitic granites has shown that in general albitised varieties contain higher concentrations of tin (and beryllium) than non albitised ones. Muscovite has been found to contain the bulk of the trace tin present in the pegmatitic granites and it has been found possible to distinguish cassiterite-bearing pegmatitic granites from non cassiterite-bearing pegmatitic granites in the tin content of the muscovites.

The relationship between albitisation and the concentration of tin in the pegmatitic granites suggests that the sodium-bearing fluids which caused albitisation may also have been responsible for the transport and concentration of tin. Muscovites from the hydrothermal quartz cassiterite-bearing veins have been found to contain higher overall concentrations of sodium than muscovites from the other mineral deposit types and it is therefore possible that sodium bearing fluids may have been responsible for the transport of tin during the formation of the hydrothermal veins.

Theories have in the past been put forward (see p.122) that tin may be transported in the form of alkali-stannates or alkali-hydroxy-fluo-stannates during the formation of certain types of hydrothermal and pegmatitic tin deposits. The micas from all the mineral deposits of S.W. Ankole contain fluorine, and the relatively high sodium content of the muscovites from the hydrothermal tin deposits together with the constant association of cassiterite with albite in the pegmatitic granites and granite pegmatites, strongly supports the theory that tin may be transported in the form of an alkali-hydroxy-fluo-stannate complex. It is suggested that the complex $Na_2(SnF_x(OH)_{6-x})$ may have been the major carrier of tin during mineralisation in S.W. Ankole.

Traces of tin (up to 600 ppm) have been found to be present in muscovites from all the mineral deposit types and to occur in at least two forms: cassiterite, and 'acid soluble' tin. Acid soluble tin has been found to make up the bulk of the tin present in the muscovites, and cassiterite is usually confined to those obtained from cassiterite bearing localities. The 'acid soluble' tin may consist of two components; lattice tin (which can be released by decomposition of the muscovite in hydrofluoric acid), and Varlamoffite (hydrated stannic oxide) which may be adsorbed onto the muscovite (and can be removed by leaching the muscovite with mineral acids which do not readily attack the lattice).

A study of the relationship of the alkalis to one another in muscovites from the mineral deposits and pegmatitic granites has shown that there is an antipathetic relationship between the K_2O and Na_2O, and K_2O and combined $Na_2O + Rb_2O + Cs_2O$ contents and a sympathetic relationship between the Rb_2O and Cs_2O contents. A sympathetic relationship between the Li_2O and F contents has also been observed. The relationships are believed to reflect the various possible isomorphous substitutions that can occur in the muscovite lattice.

It has been found that it is possible to distinguish the muscovites from the hydrothermal cassiterite-bearing quartz veins from those from other deposit types on their alkali and tin contents, and geochemical parameters have been obtained by which it is possible to use muscovite as an indicator in prospecting for tin deposits. In S.W. Ankole, muscovites containing less than 9.8% K_2O and more than 250 ppm. of Sn are almost specific indicators of hydrothermal cassiterite-bearing deposits.