

A STUDY OF PART OF THE IRUMIDE FOLD BELT,
CENTRAL ZAMBIA, WITH SPECIAL REFERENCE TO
THE GRANITIC GNEISSES, THEIR PETROGENESIS
AND REGIONAL SIGNIFICANCE

BY

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ABSTRACT

Some 200 sq km of the Chisomo quarter degree sheet, Zambia, was mapped in detail in order to study a mixed sequence of biotite-K-feldspar, porphyroblastic, fine-grained aplitic, and migmatitic gneisses. The rocks had previously been correlated with the Mkushi Gneiss Group of the Basement Complex on structural and lithological grounds. The formation of these gneisses is now shown to pre-date the Irumide and Tumbide fold phases and to have occurred syn- and late-kinematically with respect to the first fold phase of the Kiboran Orogeny. A petrogenetic model for the four major gneiss groups is proposed, based on their field relationships, petrography and chemistry. The rocks are shown to have developed progressively from metasediments by processes of blastic mineral growth, metasomatism and anatexis and conform to a typical granite series. The metasediments have traditionally been correlated with the Muva, a post-Basement Complex, pre-Katanga 'System' metasedimentary division. It is now proposed that the Mkushi Gneiss Group represents autochthonous and para-autochthonous granitic derivatives of the Muva.

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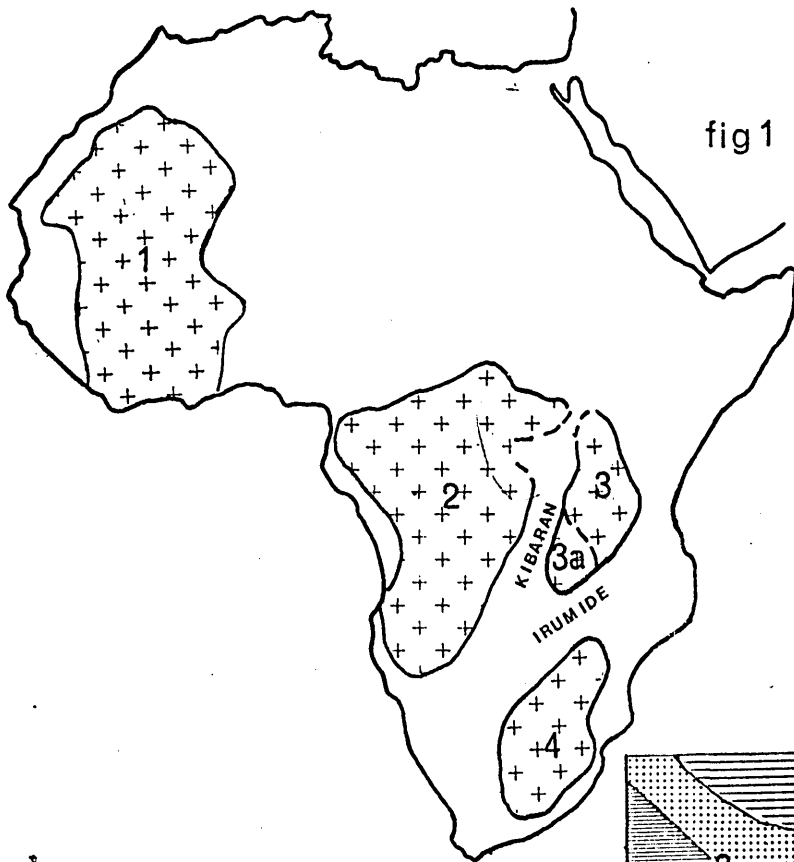
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1. INTRODUCTION

The aim of this thesis is to present field evidence and petrographic data which lead to a major reinterpretation of the development of the gneisses of the Irumide Fold Belt. An area of approximately 200 sq km in the Irumide Fold Belt, within the Chisomo quarter degree sheet, Serenje District of Central Province, Zambia, was chosen for detailed study. The area is bounded by latitudes $12^{\circ}37'S$ and $13^{\circ}45'S$ and longitudes $30^{\circ}45'E$ and $30^{\circ}52'E$ (Figure 2). It occupies a central position in a horst-like zone between the Lukusashi and Luangwa valleys and consequently is characterised by rugged terrain and good outcrop. Traverses at 500 metre intervals were made north-south across the strike and samples for petrographic study collected at between 250 and 500 metre intervals. Chemical analyses of selected samples were carried out in the Geological Survey Department, Zambia, by X-Ray Fluorescence techniques. The analytical information is incorporated where relevant to supplement the field and petrographic observations.

1.1 Structural Setting of the Irumide Fold Belt

The Irumide Fold Belt lies to the southeast of the Zambia Nucleus of Clifford (1970) Figure 1. The Irumides were defined by Ackermann (nd) as a distinctive northeast to north-northeast-trending belt of metamorphic rocks in the Central and Northern provinces of Zambia. Ackermann's work (ibid) defined two main structural trends. An early one, produced by the Tumbide Orogeny, shows predominantly north-south trends and affected an early basement of Mkushi Gneisses. A later Irumide Orogeny affected the Mkushi Gneisses and the younger overlying metasediments of the Kalonga and Musofu series resulting in dominantly north-east trends. An unconformable relationship between the Mkushi Gneisses and the Kalonga-



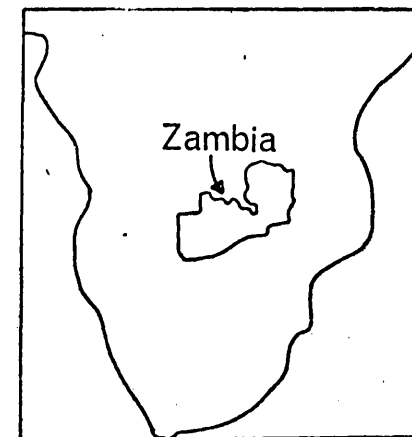
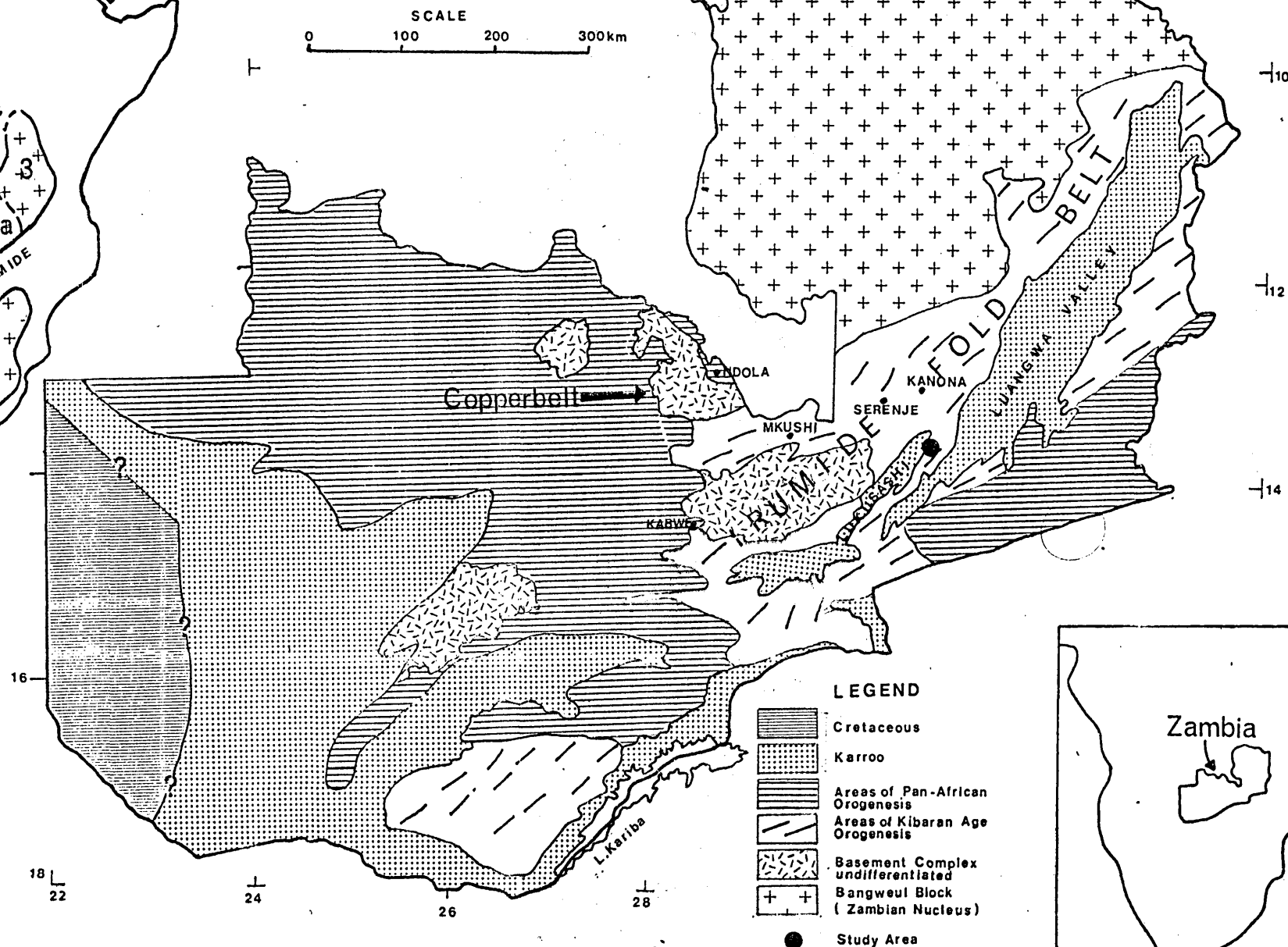
AFRICAN CRATONS DURING THE KIBARAN OROGENESIS

- 1 West Africa Craton
- 2 Angola-Kasai Craton
- 3 Tanzania Craton
- 3a Zambian Nucleus
- 4 Rhodesia-Transvaal Craton
- Blank - zones affected by Kibaran and younger Pan-African orogenesis

(AFTER CLIFFORD, 1970)

REPUBLIC OF ZAMBIA GEOLOGICAL OUTLINE

(AFTER DRYSDALL ET.AL.1972)



Musofu metasediments was postulated.

In a review of the tectonic framework of Zambia, Drysdall et al (1972) relegated the Tumbide and Irumide Orogenies to phases of the Kibaran tectogenesis. Age determinations from the Irumide Fold Belt fall within the limits of 1800 my to 875 my set by Cahen (1970) for the Kibaran Orogenic Cycle.

Snelling et al (1972) reported Kibaran ages of c 1130 my from the northern end of the Irumide Fold Belt and Snelling et al (1964) reported an age of 1625 ± 50 my for the Mtuga Aplite, 45 km southwest of Mkushi. Stillman (1965) suggested, from the fresh unaltered nature of the rock, this age might represent the true age of intrusion and be associated with the Tumbide folding. Ages of 1925 ± 20 my and 1750 ± 50 my from the Mufulira and Roan Antelope granites (Cahen et al, 1970) possibly represent over-printed Ubendian ages. Relic northerly trending structures at Roan Antelope and Kamfinsa Quarry give ages of 1635 ± 180 my and $1550 \pm$ to my. (Cahen and Snelling 1966); they possibly date the Tumbide phase in the Copperbelt.

1.2 Previous Work

Reeve (1963) considered it practicable to separate the Basement Complex from the 'obviously' younger Muva rocks. This distinction was based on the early work of Gray (1929) who noted a conglomerate traceable for a short distance from the Kinandola Falls of the Copperbelt and separating basement schists comprising a younger Muva and an older Lufubu Group*. The Muvu consists of a thick alternating sequence of psammitic and pelitic metasediments (Reeves 1963 p 18). Quartzites are the predominant

* See Appendix 3 for lithostratigraphic terms.

psammites and define northeast trending ridges, a prominent feature of the Irumide Fold Belt. The Basement Complex of Reeve and Snowball (1960) is equivalent to the Lufubu Group.

Based on work in the Irumide Fold Belt, Stillman and Simpson (1963) proposed the correlation between the Mkushi-Musufu area and the Copperbelt shown in Table 1. As can be seen the Irumi Formation which is composed of psammitic schists, quartzites and sericitic schists, was placed with the Muva and distinguished from the Basement Complex. This correlation seems to have been an attempt to group all metasedimentary rocks in the Muva and to place granitic gneisses in the Lufubu System or Basement Complex.

TABLE 1

<u>Mkushi-Musofu</u>		<u>Copperbelt</u>
-----	Katangan	-----
unconformity		unconformity
Kalonga Fm		
unconformity		
Musofu Fm		Muva
faulted unconformity		
Irumi Fm	)	
no clear break	)	
Mkushi Gneiss Fm	)	
	Mkushi Group	
		Lufubu Syste,

After Stillman and Simpson (1963)

Later Stillman (1965) proposed the provisional correlation with Ackermann (1960) shown in Table 2. No clear break was defined between the Irumi and Musofu formations. 'the junction with the Irumi Formation is apparently

faulted and thrust' (Stillman *ibid.* p22). The Kalonga and Musofu formations were separated from one another on differing structural style and grade of metamorphism. The work of Stillman and Ackermann therefore showed a well defined sequence of rocks in the Irumide Fold Belt with granitic gneisses at the base succeeded by quartzites, psammitic schists and pelites. This two-fold lithostratigraphic division has also been noted by Moore (1964), Cordiner (1965) and Kerr (1971) in areas to the north-east and south-east of the Mkushi area in the Irumide Fold Belt. It is therefore reasonable to say that the outcrop of these two distinctive lithologies is extensive. These later workers made direct correlations with the Mkushi area, but the definite break between the gneisses and metasediments postulated by Stillman, was not observed.

TABLE 2

Stillman (1965)	Ackermann (1960)	Mendelsohn (1961)
-----Katanga System -----		
-----unconformity-----		
Kalonga Fm.	Bemba Beds	
	Kalonga Series	
___ unconformity ___		Muva
	Upper Muva	
Musofu Fm.	Lower Muva	
- break, position uncertain-		Granite
(Irumi Formation		
(		
Mkushi (Mkushi Gneiss		Lufubu
Group (Formation		

Moore (1964, 1965) described a sequence of metasediments from the area around Serenje which may correlate with the Kalonga and Musofu formations

and which passed to the south-east into biotite gneisses and coarse porphyroblastic gneisses, the result of feldspathisation. Only coarsely crystalline quartzites remain in the gneiss terrain as non-granitised resisters. Moore (1964) also realised that the granitisation predated a strong folding on north-east axes which may have been contemporaneous with a second feldspathisation leading to the development of porphyroblastic gneisses.

In the adjacent Kanona Area, Cordiner (1965) recognised that, as in the Serenje Area, much of the granite gneiss appears to have been derived by granitisation of metasediments, but that it is also partly reconstituted basement (Cordiner 1966). Subsequent work by Cordiner (1967) defined the Chibobo Group as an older basement granitised complex containing polygenetic, coarse porphyroblastic gneisses produced by granitisation of metasediments and older sheared basement gneisses. The relationship between the Chibobo Group, correlated with the Mkushi Gneiss Formation and the overlying Kanona Group, was later described by Cordiner (in press) as being originally unconformable, though the contact has been obliterated by granitisation. This last would seem to be an attempt to justify his correlation with the Mkushi area.

Kerr (1969, 1970) describing the Fiwila Mission Area, recognised the Mkushi Gneiss Formation and noted feldspathisation at its contact with the Kalonga metasediments which locally produced rocks with 'Mkushi Gneiss' appearance, the contact being gradational. The presence of isolated quartzite ridges in the gneiss led Kerr (1969) to believe that they were undigested remnants of the basal Kalonga Quartzite. These deductions of Kerr imply a contact between the two lithologies subsequently obliterated by feldspathisation. In the Chingombe Mission Area, Kerr (1971) concluded

from the mixed nature of the gneiss, i.e. the presence of bands of psammitic gneiss, epidote quartzites, amphibolites and concordant quartzite horizons, that the entire Mkushi Gneiss Formation was derived from meta-sediments. However, in a description of the Nickete Anticline in the Fiwila Mission Area, (Kerr in prep) Mkushi Gneiss was described as having apparently broken through a quartzite limb leaving xenolithic remnants. An intrusive origin was suggested for this feature.

Page (in press) interpreted the Escarpment Gneiss Formation of the Chilonga Mission Area as a relic of an original basement, modified by granitisation and remobilisation. He correlated the Escarpment Gneiss Formation with the Chibobo Group of Cordiner and the Mkushi Gneiss Group.

Hickman (1973 in prep) divided the basement rocks of the Bulonga Hills into a Gneiss Group and a Metasedimentary Group. The Gneiss Group of biotite, porphyroblastic K-feldspar gneisses and muscovite gneisses was thought to be of igneous origin and older than the metasediments (ibid 1973). This group was correlated with the Mkushi Gneiss Group (ibid in prep).

The presence of pink, muscovite and biotite gneisses associated with the porphyroblastic gneisses has been noted by the earlier workers. Kerr (1969) and Stillman (1965) described sheets and bands of fine-grained pink, muscovite gneiss in the Mkushi Gneiss Group. Cordiner (in press) noted that the leucogneisses were younger than the biotite, porphyroblastic K-feldspar gneiss. This relationship was confirmed by the author (Klinck 1973, in prep) who also noted intrusive contacts between the younger, pink granitic gneisses of the Mwila Gneiss Group and the older biotite, porphyroblastic K-feldspar gneisses of the Nkondo Group.

From the above outline of previous work it is evident that there is a widely distributed sequence of biotite, porphyroblastic K-feldspar gneisses and leucocratic, biotite and muscovite gneisses in the Irumide Fold Belt. The gneisses have been interpreted as:

- a) a pre-Muva basement gneiss complex (Ackerman 1960, Stillman 1965)
- b) a gneiss complex derived by feldspatisation of the Muva metasediments (Moore 1964, 1965)
- c) a remobilised pre-Muva gneiss complex feldspathising and intruding the overlying Muva. (Cordiner 1967, Kerr 1971, in prep.) and
- d) an orthogneissic basement (Hickman 1973).

In the following account, using the Chisome Area as an example, it will be deduced that an original Muva sedimentary sequence was transformed into an autochthonous and para-autochthonous gneiss complex by processes of mineral growth, metasomatism and anatexis operating at different structural levels. It will also be shown that the rocks provide an excellent example of part of the Granite Series of Read (1955).

1.3 The Chisomo Area

The main structural feature of the area is the dominant north-east to east-north-east Irumide trend. This trend is especially well displayed by the Lubo Quartzite horizon. As in the Bulonga Hills area to the south-west Hickman (in prep.) and the Kanona area to the north-east (Cordiner, in press), two well defined lithological groups are recognised. Metasediments comprising quartzites, schists and calc-silicates and referred to the Mililo Supergroup and dominantly crystalline granitic gneisses. The main granitoid lithologies are migmatitic granites, microcline-muscovite granite

gneisses and biotite, porphyroblastic K-feldspar gneisses. The metasediments form a distinct belt within the granite gneiss terrain. Based on continuity of outcrop, lithological and structural similarities, and field relationships, correlations may be made with adjacent areas as shown in Table 3.

TABLE 3. LITHOLOGICAL CORRELATIONS

CHISOMO	KANONA (Cordiner)	BULONGA HILLS (Hickman)
Mililo Supergroup	Kanona Group	Metasediment Group
Mwila Gneiss Group) Migmatite Gneiss Group)	Chibobo Group	Gneiss Group
Nkondo Group)		

It should be noted that no stratigraphic sequence is implied: a stratigraphic reinterpretation of the Irumide Fold Belt will be proposed later.

Using the above lithological criteria (p. 19) the gneiss groups of the Chisomo Area may also be correlated with Mkushi Gneiss Formation and the Milolo Supergroup with the Musofu and Kalonga Formations.

1.3.1 Structural Framework

There is a very strong structural control on outcrop distribution and the pre-Karoo deformation phases described by Klinck (in prep.) are summarised in Table 4. The first three deformation phases in the Chisomo Area had common structural elements and their interference gave rise to the prominent north-east structural trend.

TABLE 4

D ₅	F ₅	Open recumbent folds on NE axes approximately coaxial with F ₁ and F ₃ .
D ₄	F ₄	Open upright folds on NW axes.
D ₃ Irumide Phase	F ₃	Upright open to tight folds on NE axes. 1 ₃ crenulation in pelitic layers and strongly foliated gneisses.
D ₂ Tumbide Phase	F ₂	Isoclinal folding on N to NW axes. Strong b lineation developed. Axial planes are approximately coincident with S ₁ . Augen textures and elongate quartz mosaics formed. Locally blastomylonitic.
D ₁	F ₁	Isoclinal folds with shallow plunge NE. Axial planar schistosity S ₁ .

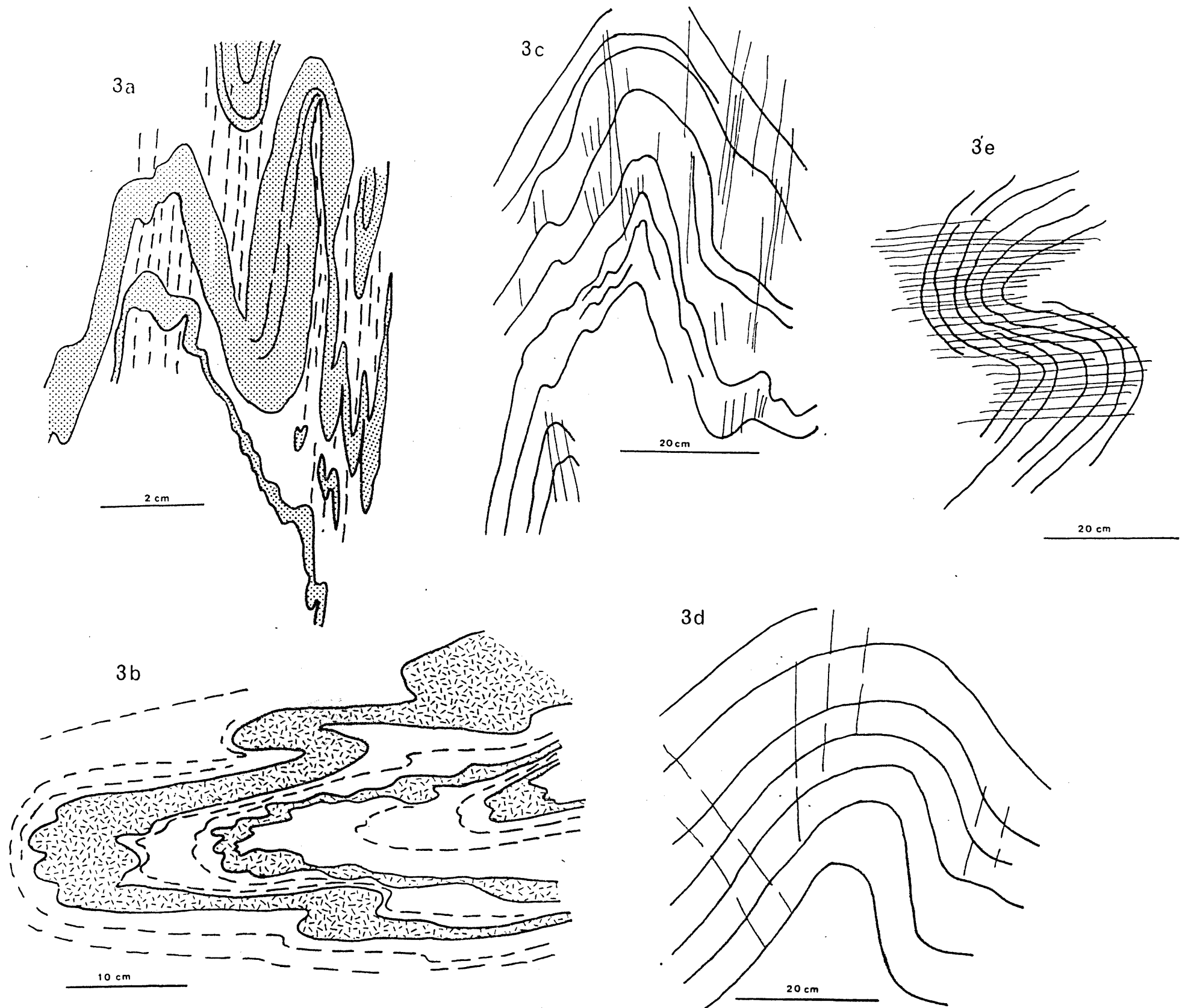


Fig3 Fold styles developed in the Chisomo Area

1.3.1.1 The First Deformation D1

D1-folds have not previously been described and their existence in the Chisomo Area has been deduced from fold interference patterns. (Klinck, 1973, in press). As would be expected from such a prolonged structural history examples of F1-folds are rare but there are examples in the Mililo Supergroup Fig. 3a. The folds tend to be isoclinal with parallel limbs, a strong axial planar schistosity is developed and quartzitic banding may be transposed into the schistosity producing a tectonic banding. Fold noses become obliterated, and intrafolial folds can develop. On fold hinges which show a shallow north-east plunge a rodding/intersection lineation may be preserved. The recognition of D1-fold structures in the Chisomo area offers an explanation for pre-Tumbide foliation present in the Mkushi Gneiss Group and suggests that a major structural reinterpretation is necessary.

1.3.1.2. The Second Deformation D2: Tumbide Phase

This phase is well represented throughout the area and good examples of mesoscopic F2-folds can be seen in banded migmatites Fig. 3b. The folds are generally isoclinal with the limbs long compared to the width. They fold already developed S1 and tectonic banding from D1. A strong pervasive b-lineation occurs which is responsible for the north to north-west Tumbide orientation. The b-lineation associated with this fold phase often produces mullion structures in thin quartz veins and probably represents relic fold hinges. Axial planes strike north-east and an axial planar schistosity is developed in the axial zones of folds that may locally result in a crenulation in pelitic layers. Texturally the cataclastic effects of this D2-deformation are most pronounced in the more competent gneisses where blastomylonitic and augen textures are formed. The work of Ramberg (1964) offers an explanation for the lack of F2-fold development in the more

competent gneisses relative to the banded migmatites and metasediments. Under compressive stress Ramberg (ibid) showed that more competent or viscous horizons shorten whilst less viscous horizons, in this case the migmatites and metasediments, are folded. The parallel limbs of F2-folds indicate high compressive stresses and this possibly led to the blastomylonitic type foliation seen in the gneisses.

Hickman (in prep.), describing the Bulonga Hills area, attempted a structural correlation with surrounding areas. From D2 onwards there is good agreement and a correlative of D2 may be found throughout most of the Irumide Fold Belt. The strong b-lineation has been described by a number of previous workers, eg Reichwalder (1973), Moore (1965), Cordiner (in press) and Stillman (1965). In the following discussion of the gneiss groups it will be shown that their petrogenesis predates the D2-textures, ie they were formed before D2 and are thus pre-Tumbide. Further, the Mililo Supergroup metasediments which show D1 folds must also predate D2, the Tumbide Phase. The Mililo Supergroup may be correlated with the Muva or the Irumi Formation of Stillman (1965), but the fact remains that it is pre-Tumbide.

Interference patterns developed between F1 and F2 folds have not been recognised and it may be interpreted from this that they are now coaxial planar and that the b-axes are at right angles in the F2-axial plane. However, a north-east F1-trend may be deduced, consistent with observations.

1.3.1.3. The Third Deformation D3: Irumide Phase

The resultant folds are tight upright similar folds with north-east trending axes Fig. 3c. On a mesoscopic scale an axial b-lineation is locally developed and there is a strain slip cleavage in some of the thin pelitic layers. The strain slip cleavage is also locally developed in strongly D2-tectonised

gneisses. (Plate 88) and quartz ribbon foliation is folded.

Fig. 4a shows a map of second deformation lineations which define a sigmoidal trace across the area. The pattern developed is due to folding of north-south lineations on the north-east Irumide Trend. A plot of poles to schistosity Fig. 4b confirms the presence of north-east folding and the form of the maxima indicates folds with a tight hinge zone, hence the lack of any data in the central part of the girdle. Vertical schistosity readings on the fold axis Fig 2 may be an S3-axial planar schistosity. The contact between the Mwila Gneiss Group and the Nkondo Group appears to be folded by F3 and indicates that these two gneiss groups are pre-Irumide phase (pre-D3).

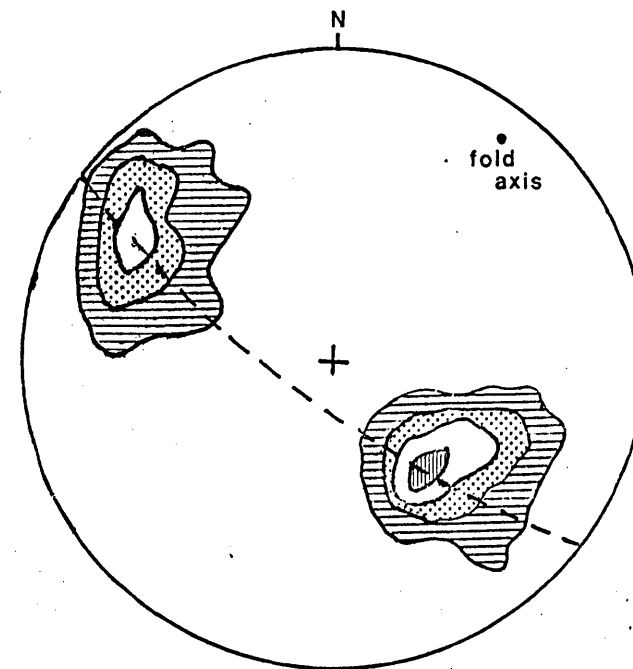
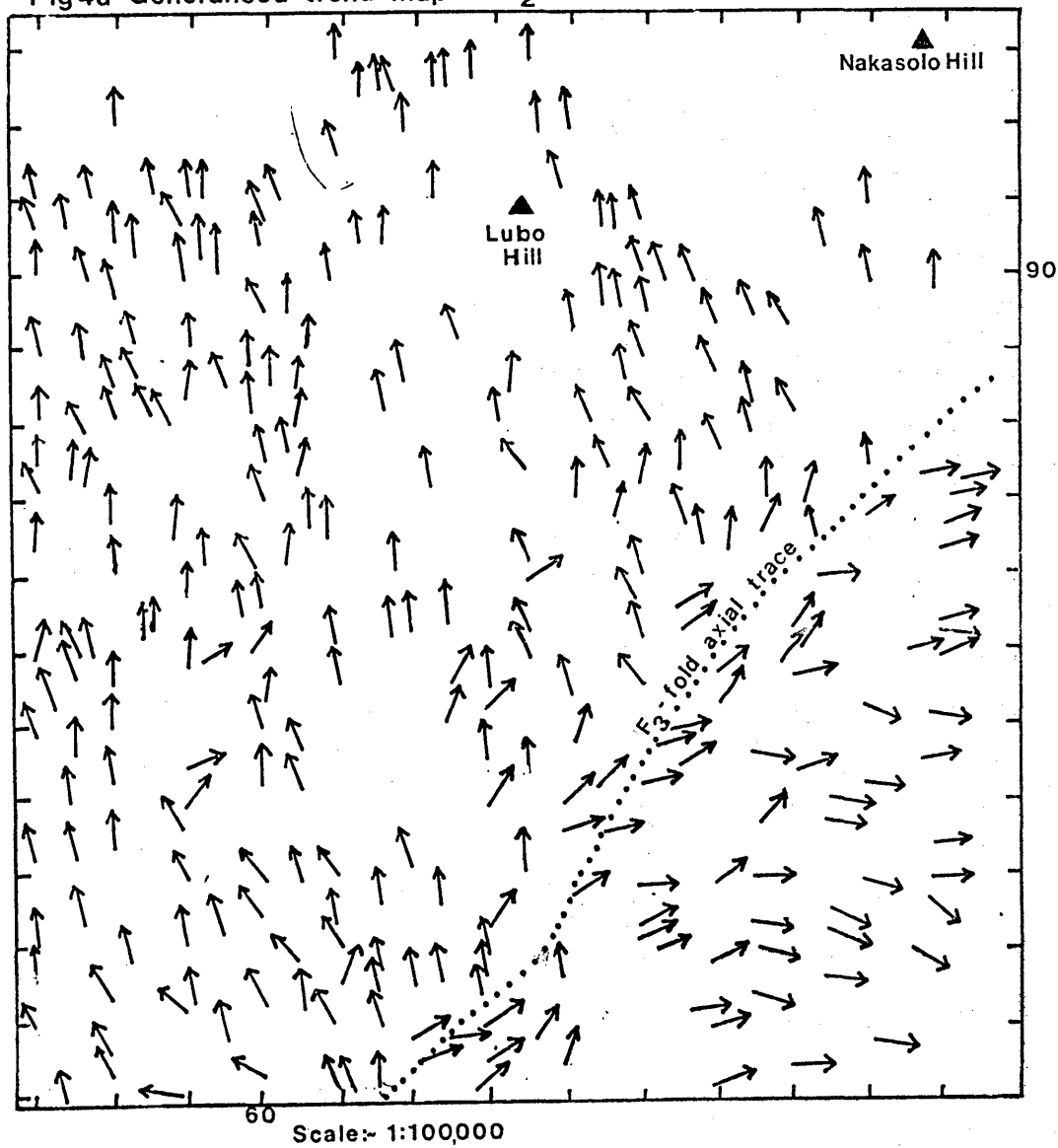
F3 on F2 interference patterns are developed, type 2 of Ramsey (1967). Their recognition confirms the north-west axial trace of F2 and the north-east trace of F3. To produce these patterns F2-folds must be reclined and isoclinal and F3-folds upright.

Rare cases of F3 on F1 interference have been noted and F1 is coaxially refolded about F3, a further proof of north-east F1-axes.

1.3.1.4. The Fourth Deformation: D4

Open upright folds on north-west axes characterise this phase which was not a major tectonic event. The swing of quartzites about north-west axes is attributed to this phase. Mesoscopic examples tend to be parallel buckle type folds. Fig 3d. F4 on F2 interference produces type 3 interference patterns (Ramsey 1967), indicating a near coaxial relationship between F4 and F2 with F2 showing a steeper plunge than F4. F4 on F3 produces typical type 1 to 2 basin and dome and local mushroom patterns.

Fig4a Generalised trend map of L₂-lineations



4b) 250 poles to S₂, contours 2.4, 6 & 8%
(Equal area, lower hemisphere projection)

1.3.1.5 The Fifth Deformation: D5

Like the fourth deformation, D5 was of little tectonic significance in the development of the overall structural framework. F5 folds are typically developed in the pelitic zones with recumbent axial planes and, usually, a well defined strain slip cleavage. Fig.3e. The second deformation lineation is folded around the fold hinge zones and is almost at right angles to b5. Finite neutral points are formed in the hinge zones of competent folds and characterise parallel, buckle folds. D5 is inferred to be the last recognisable structural event from the almost constant orientation of F5-axial planes.

1.3.2. Metamorphism

The relationships between metamorphism and deformation have been deduced from thin section study using the criteria of Spry (1969).

Two main episodes of metamorphism have been established in the upper amphibolite facies with a late retrogression into the greenschist facies. The first metamorphism was syn-kinematic with D1 while the second metamorphism occurred post-kinetically to D2 and persisted into the D3-phase. There is no evidence for a metamorphic break between D2 and D3, the Tumvide and Irumide phases respectively. From this it might be postulated, following Drysdal et al. (1972), that neither is there a marked structural break between the two phases.

The metamorphic development of the rocks is discussed more fully as each group is described below.

2. THE MILILO SUPERGROUP

This supergroup comprises all those rocks which show metasedimentary characteristics, in particular compositional banding, or typical metamorphic mineral parageneses derived from sedimentary rocks. It has not been possible to establish a stratigraphy within this supergroup because sedimentary structures, providing way up evidence, were not observed. The following main groups have been recognised: the Lubo Quartzite Group, the Biotite Schist Group, the Calc-Silicate Group and the Nkonsolo Group. These groups show continuity of outcrop on the dominant north-east trend and layers of such metasediments are recognisable throughout the area.

2.1 THE LUBO QUARTZITE GROUP

This Group is named after Lubo Hill (TV 631903)* and forms prominent features. The outcrop defines a distinct, marker horizon in the northern part of the area. On air photographs the banded nature of the outcrop is seen, illustrated by trend lines on Fig. 2, the banding being picked out by weathering, particularly of more micaceous horizons. Traced south-west, the main outcrop thins and north of the Mwila River, the rocks pass into granitic gneisses.

In outcrop the rocks of the group are creamy-white, fine-grained, muscovite quartzites and in thin section the main mineral constituents are seen to be muscovite, quartz and opaque minerals. The last often define a layering paralleled by the basal planes of oriented muscovite flakes. Kyanite occurs on Lubo Hill and in thin section its long axes are seen to lie parallel to the layering and the muscovite schistosity. The orientation of the kyanite indicates that metamorphism in the amphibolite facies was syn-kinematic with the development of the schistosity parallel to opaque mineral banding which represents bedding. Sedimentary structures defined by concentrations of opaque minerals have been found outside the area of detailed study (Klinck, in prep.).

Subsequent crenulation of kyanite and the muscovite foliate with post-

*Grid references are given in relation to the Universal Transverse Mercator Grid. A unique grid reference is obtained by prefixing 36L.

crenulation polygonisation, is seen in 9FD 844*. The kyanite crenulation is related to the development of the prominent north to north-west mica extension lineation and rodding (D_2). The textural features indicate a first metamorphism during D_1 from the presence of schistosity and kyanite elongation parallel to bedding. The next event, D_2 , crenulated the kyanite and mica. No strain effects are now seen because the second metamorphism after D_2 (M_2), annealed the D_2 fabric.

As the quartzites are traced into the granitic gneisses microcline becomes an essential constituent. In extreme cases the rocks take on the appearance of the Mwila Gneiss Group. In thin section relics of the original quartz mosaic are still present and metasomatic microcline is seen to be replacing quartz along the grain boundaries.

2.2 THE BIOTITE SCHIST GROUP

The main outcrops of this group are found on the Mililo Stream and in the Mitimbe Stream north of the Lubo Quartzite Group. The rocks show a wide range of variation from pelitic to psammitic, biotite-muscovite schists. Mineral assemblages, seen in thin section, indicate that metamorphism has occurred in the upper amphibolite facies and sillimanite has been noted from a number of localities. The parallelism of the biotite foliate and the banding, defined by quartzite and pelitic layers, indicates the tight to isoclinal nature of the first folds (F_1). In the Mililo Stream (TV 575873) F_1 -fold closures of quartz-rich banding have been seen with biotite developed axial planar to the folds and at a high angle to the banding. Table 5 shows the ages of metamorphic minerals in relation to the D_1 schistosity and the D_2 crenulation. Upper amphibolite facies

*Sample numbers relate to thin sections held by the Geological Survey Department, Zambia

conditions operated with maxima during D_1 and after D_2 . According to Winkler (1974, p 273), such conditions are favourable for anatexis.

TABLE 5

Mineral growth in relation to schistosity (S_1)
and D_2 crenulation in the Biotite Schist Group

Sample No.	pre	S_1	post	S_2	post
9FD 66		sill			sill
91		sill			sill
94			garnet		
105		sill			sill, garnet
274			sill, staurolite		
340		garnet	→ staurolite		
775				— garnet → — staurolite →	
840			garnet		staurolite
842			staurolite		
844		kyanite		— kyanite →	

Table 5 illustrates that the metamorphism during S_1 was syn-kinematic and reached the upper amphibolite facies. Garnet and staurolite were locally developed post- S_1 and pre- S_2 . The regional biotite schistosity was developed at this time. The second metamorphism again reached the upper amphibolite facies, but was post- S_2 . Axial planar schistositities were developed only locally. S_1 was crenulated in the hinge zones of tight to isoclinal, F_2 -folds and the crenulations were polygonised post- D_2 . Plagioclase blastesis is shown at a number of localities, eg 9FD 165 and 340, and rocks intermediate between psammitic schist and Nkonsolo Group plagioclase blastites are present. The plagioclase grew during and after the development of S_1 , eg at TV 580833 plagioclase porphyroblasts 1-2 mm in size were formed during the development of the main foliation (S_1).

2.3 THE CALC-SILICATE GROUP

These melanocratic fine-grained, banded, amphibole-plagioclase rocks are very distinctive in the field. They mainly crop out in the west where they are surrounded by muscovite-biotite granitic gneiss of the Mwila Gneiss Group. When traced to the north-east the banding becomes thinner and discontinuous and relics on strike with the main outcrop are preserved north-west of the gneissose Mwila Granite (TV 594849).

In the southern and south-eastern part of the area narrow bands are intercalated with migmatitic gneisses. In situ outcrop is rare, the calc-silicates being characterised by oxidised float in a red brown soil. Such soil contrasts sharply with the leached acid soils characteristic of the granitic rocks. On air photographs dark-toned lineaments parallel to the regional north-east strike define the calc-silicate bands.

In the south-east the calc-silicate bands form a north-east trending 'swarm' concordant with the outcrop of the Lubo Quartzite Group. The calc-silicates are considered to be palimpsest and indicative of the autochthonous nature of the host granitoids because of the continuity of the 'swarm' through the gneisses.

2.3.1. Petrography

The rocks usually show a well-defined layering varying in thickness from 3 to 10 mm. Light layers are composed of quartz-plagioclase aggregates and the darker layers of the calc-silicate minerals diopside, tremolite (local variety edenite) and epidote. Idioblastic sphene and epidote are common accessories. The equilibrium assemblage $Di + Tr + Cc + Q$

defined by Winkler (1974, p. 119) has been noted in the eastern part of the area. To the west the dominant assemblage $Tr + Q + C_c + Ep$ is very common but in itself is not diagnostic of PTX conditions. Scapolite is an essential constituent in two samples collected near the margins of the main calc-silicate outcrop. It forms poikiloblastic/xenoblastic, platy crystals with inclusions of epidote and amphibole and is considered by the writer to be a late stage metasomatic mineral replacing plagioclase, a typical paragenesis. Microcline also occurs locally in the groundmass mosaic and replaces plagioclase and amphibole (Plate 1). Textural features of the granitic gneiss groups indicate the microcline to be pre- D_2 and therefore the equilibrium mineral assemblage is diagnostic of the first synkinematic metamorphism, M_1 .

The $Di + Tr + Cc + Q$ equilibrium assemblage is found associated with the anatectic rocks of the Migmatitic Gneiss Group and forms a prograde sequence from the $Tr + Q + Cc + Ep$ assembly found to the north-west.

2.4 THE NKONSOLO GROUP

The rocks of this group are mainly confined to a 1 km-wide band in the northern part of the area. Typically the rocks are mesocratic, medium-grained, pelitic, plagioclase gneisses. Sub-idioblastic porphyroblasts of plagioclase range from 3 to 20 mm in size and vary in colour from off-white to pale, watery green. Potash feldspar is sporadically developed, particularly towards the contact with the Nkondo Group. Lithological variations are common (Plate 2) and range from biotite psammite to pelite, the banding, where present, being defined by psammitic layers in a pelitic unit. The main schistosity is coplanar with the banding and the quartzofeldspathic leucosomes and it is inferred that the leucosomes and

schistosity formed at the same time.* The leucosomes show a biotite-rich melanosome in which biotite defines the foliation and therefore must have formed during D_1 . Evidence of F_2 -folding of the leucosomes and schistosity comes from the Chilandi Stream, north of the area of detailed study. Here the leucosomes show a fracture cleavage in the fold-hinges and carry a strong north to northwest oriented rod lineation. The limbs of these folds are extended and boudinaged and the leucosomes are therefore pre- D_2 .

The Nkonsolo Group provides a petrogenetic link between the Biotite Schist Group and the Nkondo Group which has been classed as a granitic gneiss.

2.4.1 Petrography

Straw-brown, pleochroic, tabular biotite defines the schistosity.

Muscovite is an accessory, along with opaque minerals and apatite. Quartz is the chief component of the granoblastic groundmass and also forms ribbons and polygranular eyes in and parallel to the mica schistosity. Plagioclase porphyroblasts predate this foliation, being surrounded by parallel deformed biotite flakes and quartz-ribbons. (Plate 3).

Subsequent second metamorphism (M_2) polygonisation removed most of the strain and the micas and quartz-ribbons form partially polygonised crescents around the plagioclase. Extension in the F_2 -fold limbs and the formation of the 1_2 extension lineation may have caused the development of the quartz-ribbons. This texture is particularly characteristic of the

* The words leucosome and melanosome are members of a migmatite terminology proposed by Dietrich and Mehnert (1964) and are defined along with other petrographic terms used in this thesis in Appendix 4.

granitic gneisses. The ribbons show very little evidence of remnant strain due to post-kinematic M_2 polygonisation. According to Spry (1969, p 295) the ribbon texture, characteristic of foliated granulites, is due to a combination of strong deformation and cataclasis followed by post-kinematic crystallisation and indicates that the rock is some kind of blastomylonite. The plagioclase porphyroblasts are marginally poikiloblastic and include elements of the groundmass such as drop-like quartz inclusions and early biotite. Such marginal grain features have been used by Mehnert (1968, p 43) and also Augustithis (1973, p 7) as a criterion for the recognition of plagioclase blastesis. Examination of thin sections from the Chisomo area has revealed many examples of such phenomena and plagioclase blastesis is therefore accepted as an important petrogenetic mechanism in the area. Plate 4 shows examples of pre- S_2 plagioclase blastesis; in general the groundmass is a granoblastic, polygonal mosaic of quartz and plagioclase. In 9FD 563, microcline occurs in significant amounts and plagioclase shows heavily sericitised, equant, pre-schistosity porphyroblasts in a semi-pellitic, biotite-quartz-plagioclase mosaic. Mehnert (1963, p 69) noted that plagioclase showing equant habit is characteristic of migmatites and especially plagioclase blastites. The sericitisation of plagioclase generally starts along twin planes and in some cases sericite may completely replace the plagioclase. It is noticeable that samples without microcline have fairly fresh looking plagioclase while in samples with microcline the plagioclase is generally altered. The microcline often forms pre- S_2 porphyroblasts up to 5 mm across and contains irregular, sericitised, corroded plagioclase insets. The microcline therefore post-dates plagioclase blastesis and is metasomatically introduced. Since primary microcline has not been noted in the metasedimentary groundmass of these rocks or of the Biotite Schist Group, a blastic origin similar to that of plagioclase may be discounted. In Plate 5, an early plagioclase is present in a sericitised plagioclase

which is again surrounded by fairly fresh looking plagioclase. The crystal shows irregular extinction due to its polygranular nature and here the blastic process has advanced to such an extent that adjacent crystals have merged. The presence of the irregular quartz bleb and the irregular corroded nature of plagioclase is evidence of blastesis.

Plate 6 illustrates a plagioclase porphyroblast showing late replacement by muscovite. The irregular replacive contact at the left of the crystal and the occurrence of partially oriented muscovite flakes within the plagioclase indicate that the mica replacement is metasomatic. The small inclusions tend to show a preferred orientation along twin planes. Sericitisation has occurred at the bottom right of the plate.

3. THE GRANITIC GNEISS GROUPS

These groups have been differentiated by their granitic aspect, K-feldspar being an essential constituent.

Petrographically the gneisses all show a very similar development and this will be emphasised in the following sections. Recognition of this is of major importance in interpreting the genesis of the gneiss groups, the main diagnostic characters of which are summarised below.

- a) The Nkondo Group This group is characterised by mesocratic biotite porphyroblastic K-feldspar gneiss with a well-developed foliation, locally blastomylonitic. Commonly encountered enclaves include quartzite and psammitic, biotite schists; these are generally sub-rounded or sub-angular, elongated in the foliation.
- b) The Mwila Gneiss Group is characterised by pink or rose coloured fine to medium grained muscovite and biotite gneisses with an aplitic aspect. Enclaves are rarely encountered.
- c) The Migmatite Gneiss Group may be subdivided into two main lithologies, one consisting of biotite, banded gneisses showing migmatic segregation structures and the other a granitic phase which is generally white to pale pink, medium and coarse grained with numerous enclaves of both quartzite and recognisable rocks of the banded gneiss phase. Weathered surfaces show the idioblastic nature of plagioclase.
- d) The Chibambila Group is generally composed of pink, coarse grained pegmatitic gneisses with common bands of muscovite quartz schist and

quartzite. The enclaves of this group differ from c) above by not showing migmatic segregation but rather assimilation into the pegmatitic gneisses by feldspathisation.

3.1 THE NKONDO GROUP

This group comprises a very distinctive lithology of mesocratic, medium to coarse grained biotite, porphyroblastic K-feldspar, plagioclase, gneisses. They tend to produce flat pavement-type outcrops and, in more dissected areas, rounded, upstanding inselbergs with little or no soil cover. Three well-defined north-east-trending bands occur in the area (Fig 2). The north-west band is approximately 1 km wide and associated with metasediments of the Biotite Schist Group, but on air photographs it is easily differentiated from the metasediments by the lower density of trend lines. The central band is approximately 2 km wide and associated with the Lubo Quartzite and the Mwila Gneiss. The south-east band is more irregular and less than 1 km wide in migmatitic gneisses of the Migmatitic Gneiss Group.

In the northwest of the map area, the contact of the Nkondo Group with the Biotite Schist Group is gradational through a discontinuous and narrow zone of plagioclase blastites. These show marked metasedimentary affinities in both mineralogy and in the alternations of narrow psammitic and pelitic layers. The plagioclase blastites are similar to those of the Nkonsolo Group, differing only in the smaller size of porphyroblasts. A mappable band of plagioclase blastite within the Nkondo Group occurs at TV580890; away from the contact are abundant biotite psammite enclaves. At TV620903 the porphyroblastic gneiss contains a lens of biotite, porphyroblastic garnet, semi-pelite which can be traced into the main metasedimentary outcrop. The contact with the metasediments is megascopically

concordant. This same concordance is particularly well demonstrated at TV 635929 where the Nkondo Group is in contact with a thin banded quartzite lens in biotite psammite. The quartzite lens is concordant with the outcrop of the Lubo Quartzite.

The contact between the Nkondo Group and the Lubo Quartzite is seen on air photographs to be sharp and concordant. However, work southwest and east of Lubo Hill (TV 634909) showed an apparent intrusive contact. At TV 641909 a stream traverse across the exposed junction showed grey, medium-grained, granular, banded quartzite resting on porphyroblastic gneiss. Within the porphyroblastic gneiss and just below the contact, thin lenses and bands of quartzites are concordant with the base of the main quartzite outcrop. South of the Mililo Stream at TV 629903 the Lubo Quartzite crosses the stream as a band not more than 1 metre thick and within porphyroblastic gneiss. It joins the main outcrop north of the stream. Klinck (in prep.) has noted a zone of enclaves, through which the Lubo Quartzite can be traced, between Nakasolo Hill (TV 687930) and Ngulubile Hill to the northeast within porphyroblastic gneisses. This fact, plus the contact relationships already described, suggests passive emplacement of the Nkondo Group rocks. The contacts may be interpreted as metasomatic fronts, the large megascopic quartzite enclaves (eg, TV 651910) south of the Lubo Quartzite representing relics. The irregular nature of the quartzite bands southwest of Lubo Hill and Nakasolo Hill suggests that here, pelitic and semi-pelitic intercalations have been more readily replaced, leaving the resistant quartzitic lithologies as recognisable bands. In the western part of the area much of the ground is occupied by the Mwila Gneiss Group. In the Mwila Stream, bands of Mwila Gneiss occur in the Nkondo Group with apparent conformable contacts. Plate 9 shows such a relationship: note the development of augen in the

Nkondo Group towards the contact indicating a marked difference in competence between the two lithologies and their existence pre- D_2 - the augen forming event.

The outcrop pattern north of the Mwila Stream indicates an intrusive contact between the Nkondo Group and the Mwila Gneiss Group. Dykes and veins of the Mwila Gneiss cut the porphyroblastic gneiss. On the Nkonsolo Stream the contact between the Nkondo Group and the Mwila Gneiss Group is sharp. Plates 10 and 11 show enclaves of the Nkondo Group within the Mwila Gneiss Group indicating that they predate the Mwila Gneisses. From TV 655852 comes an example of a dyke of Mwila Gneiss (Plate 12) apparently intruding Nkondo Group. As can be seen, the schistosity (S_2) in which the augen are contained in the Nkondo Group cuts across the dyke margin and foliates the dyke. This is further evidence for the pre- D_2 age of the Mwila Gneiss Group. Plate 13 shows a rounded enclave of the Nkondo Group (N) within the Mwila Gneiss Group (M).

The main outcrop of the Migmatitic Gneiss Group occurs on the eastern margin of the area and is in contact with the Nkondo Group. To the southeast the Nkondo Group occurs as a band in the Migmatitic Gneiss Group. At TV 655845 a mappable skialith of Nkondo Group rocks occurs within the migmatitic gneisses and at TV 670820 an enclave of porphyroblastic gneiss shows ptygmatic leucosomes, locally taking on a nebulitic appearance. The contact relationships suggest intrusion of the Migmatitic Gneiss Group into the Nkondo Group and local assimilation.

On the basis of field evidence the Nkondo Group is deduced to post-date the Mililo Supergroup metasediments because of the presence of meta-sedimentary enclaves within the Gneiss. The Nkondo Group predates D_2S ,

the gneisses locally show well-developed augen textures, ascribed to D_2 , and a prominent rodding and mica extension lineation. The porphyroblastic gneisses also predate the Mwila Gneiss Group and the Migmatitic Gneiss Group and enclaves of Nkondo Group occur in both gneiss types indicating its earlier origin.

3.1.1 Petrography

3.1.1.1 Gneiss

The rocks show a well developed, distinctive, tectono-banded structure. Biotite defines a planar foliation with a lenticular quartz-ribbon fabric often observable in hand specimens. This fabric is particularly well developed in rocks showing the strong north-west, b, extension lineation, l_2 , which is coaxial with F_2 , tumbide-trending folds. This characteristic fabric is attributed to D_2 and is used as a structural datum in delimiting the relative ages of the textural features and relationships described below.

The schistosity is predated by pink, sub-idioblastic K-feldspars which are often extended in the schistosity to form augen. Plate 7 shows a well-banded variety with augen of K-feldspar. The leucocratic bands represent strongly tectonised, extended K-feldspar porphyroblasts. In some outcrops there is a preferred orientation of K-feldspar C-axes in l_2 , eg, in Plate 8 which shows sub-idioblastic K-feldspar porphyroblasts with a weak linear preferred orientation. The porphyroblasts range from less than 1 cm up to 15 cm in length. Rounded pre-schistosity porphyroblasts of plagioclase up to 5 mm are usually milky white to very pale, watery green in colour.

Biotite with α , straw-brown, β , γ , dark brown forms sub-idioblastic flakes defining a schistosity. The grain size is rarely in excess of 1 mm but there are larger polygranular clots in the foliation. The effects of D_3 are rarely pronounced, due to the competent nature of the rock. A weak, polygonised crenulation may be present. The foliation deforms around plagioclase and K-feldspar porphyroblasts, and is polygonised, indicating the post- D_2 age of M_2 . In hand specimens a well developed mica extension, D_{21} , lineation is apparent.

Quartz is developed in two forms. The first is as elongate lenticles and ribbons between 0.5 and 1.0 mm thick and aligned in the schistosity. Subgrain boundaries are developed perpendicular to the margins of the ribbons, M_2 polygonisation is generally incomplete, and strain extinction is still present. This fabric, as already pointed out for the Nkonsolo Group, is considered to be characteristic of cataclastic rocks and the elliptical eye-shaped swellings in the ribbons are blastomylonitic texture. It is these 'eyes' that are elongated in the b-extension direction and define the prominent D_{21} rodding lineation.

The second mode of occurrence is in the groundmass mosaic. Here the grain size varies between 0.1 and 0.3 mm and grain boundaries are straight or slightly curvilinear, meeting in triple points. This is a post-deformational annealed texture and may be described as granoblastic polygonal. No remnant strain is apparent. The combination of this texture and the quartz-ribbon texture gives rise to the classic granulite texture (Spry, 1969, p 295). NB. These are not granulite facies rocks.

It is concluded that the foliation developed in an already existing granitic rock during a period of D_2 cataclasis. Annealing during a subsequent metamorphic, M_2 , event removed many of the strain effects of D_2 .

Plagioclase forms sub-idioblastic grains of variable size. It occurs with quartz in the granoblastic groundmass mosaic and also as sub-idioblastic porphyroblasts up to 5 mm in size. The composition, determined by the Rittman Zone Method (Emmons, 1943) varies from oligoclase to sodic andesine. In the groundmass, crystal faces may be developed and textural relationships are the same as those of the porphyroblasts, although in some instances the smaller crystal size has favoured late sericitisation causing complete mimetic replacement, leaving only felted, sericitic pseudomorphs. The porphyroblasts and the groundmass plagioclase show pre-kinematic relationships to the mica-quartz ribbon foliation. This foliation curves around the pre-kinematic crystals and is polygonised. Plates 15 and 16 show equant plagioclase porphyroblasts. In Plate 15, patchy sericitisation has taken place and the included quartz on the grain margin indicates blastic growth into the groundmass. Plate 16 is a further example of this blastic process and here also a polygonised quartz-ribbon curves around the porphyroblast. Further proof of the pre-kinematic origin of the plagioclase comes from examples which show twin plane deformation in dominantly augen-ribbon textural groundmasses. Plate 17 illustrates a polycrystalline porphyroblast, represented by two generations of plagioclase, and shows twin plane disruption at right angles to the twin planes. A second weak cleavage is developed oblique to the twin planes which, with the cleavage planes, were preferentially sericitised. Partial inclusions of quartz and biotite indicate the blastic origin of this porphyroblast. Twin plane sericitisation is generally well advanced in most samples, but sericitisation also occurs in irregular patches. Muscovite nucleates on sericite and is often crystallographically oriented in the plagioclase host, a relationship for which Augustithis (1973) proposed a metasomatic origin. In Plate 20, muscovite has replaced earlier plagioclase. The relative age of muscovite has been worked out from Sample 9FD 557, in which a plagioclase showing seriticisation and crystallographically oriented muscovite has been marginally replaced by

microcline. The microcline has advanced into the plagioclase and the muscovite inclusions were incorporated into the microcline without any apparent alteration. In Plate 18, an alternative relationship with microcline is illustrated. In this example, the plagioclase has been replaced along an irregular margin; it is sericitised, but shows a clear rim against the microcline. Within the microcline, irregular plagioclase insets occur which also show a clear rim which it is thought may be a reaction product between plagioclase and microcline. A more common textural relationship with microcline is illustrated in Plate 20. Here a polycrystalline plagioclase may be recognised, composed of two distinct plagioclase grains in different optical orientation. The boundary where the two grains have coalesced is defined by a line of drop-like quartz inclusions, representing groundmass remnants trapped when the two crystals merged. As can be seen, this composite plagioclase occurs in an embayment of a microcline porphyroblast and the contact area is filled by myrmekite. Marmo (1971, p 165) in a review of myrmekitisation favoured a metasomatic origin for myrmekite and Mehnert (1968, p 201) noted that the amount of quartz produced in the characteristic vermicular blebs in myrmekite is dependent on the anorthite content of the original plagioclase, more calcic plagioclase yielding thicker quartz rods than sodic plagioclase. The question of the origin of these alteration textures is considered further in the next section on K-feldspar.

The genesis of the textures associated with plagioclase is therefore fairly straightforward. Blastesis of plagioclase in the groundmass was the earlier event, indicated by inclusions of typical groundmass components such as quartz and micas, see, eg, Plate 19. The plagioclase was then sericitised and secondary muscovite developed with preferred orientation

in the plagioclase host, especially along twin planes. All these events occurred pre-D₂ and are therefore related to the first metamorphism, M₁. With the replacement of plagioclase by microcline both the myrmekite texture and the clear albite rims to plagioclase in contact with microcline developed.

K-feldspars appear to be idioblastic in hand specimens, but in thin sections they show sub-idioblastic to xenoblastic outlines. The dominant K-feldspar is microcline and perthitic orthoclase is of less frequent occurrence.

The microcline is pre-kinematic with respect to the quartz-ribbon texture (Plate 21). The quartz-ribbon and biotite foliation is polygonised around the porphyroblast indicating the post-kinematic age of M₂. The margins of the porphyroblasts in contact with the groundmass mosaic show embayments against quartz. In Plate 22, there is evidence of microcline migrating along grain boundaries and including the groundmass. This is the characteristic, metasomatic, poikiloblastic texture of microcline. Further evidence of the pre-ribbon texture age of the porphyroblasts comes from the recognition of deformed twin planes in microcline.

Two phases of microcline growth are clearly distinguishable in thin section. The pre-ribbon age of some of the microcline has already been established. However, Plate 23 shows an example of microcline replacing a quartz-ribbon along grain boundaries and indicating a post-ribbon age for the microcline. The inference therefore is that during M₂ annealing of the quartz-ribbons further mobilisation occurred giving rise to the development of a second generation of microcline.

Further examples of microcline replacing the quartz mosaic are shown in Plates 24 and 25. In Plate 24, marginal growth of microcline into the quartz mosaic has led to the partial replacement of a quartz grain, producing a small quartz inclusion which is in optical continuity with the external grain. A plagioclase inset which shows sericitisation is also present. Smaller xenoblastic remnants of plagioclase occur in optical continuity in the microcline host and indicate the former extent of the plagioclase. Plate 25 shows a groundmass microcline replacing a quartz mosaic: it has embayed, irregular margins. Generally, in the groundmass, the form of the microcline is dependent on the tectonic history of the rock. In strongly D_2 -tectonised varieties it forms xenoblastic, elongate grains in the foliation but in less tectonised examples, showing a weakly developed ribbon fabric, a polygonal habit is adopted with curvilinear grain boundaries. Local aplitic patches develop showing this latter texture.

As previously mentioned, perthitic K-feldspar does occur and usually shows textural relationships to the groundmass comparable to those of microcline. In Plate 26, a perthitic orthoclase porphyroblast contains a septum of quartz/feldspar mosaic which may be traced from the porphyroblast into the groundmass indicating that this has also been replaced by perthitic K-feldspar.

Alteration of microcline is only rarely observed and generally it is quite fresh in comparison with the coexisting plagioclase. The usual alteration products are sericite and carbonate. In Plate 27, a microcline porphyroblast is cut by a reticulating network of carbonate-muscovite veins which must represent post-microcline metasomatic alteration.

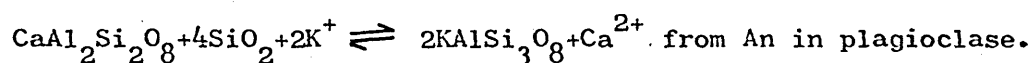
The relationships between microcline and plagioclase were noted previously in the section on plagioclase, eg, Plate 28 which shows a corroded plagioclase inset enclosed in microcline microperthite; the latter is embayed by myrmekite, but the plagioclase inset is apparently unaffected. The question is how is it that several different microcline-plagioclase textures may develop in the same rock type? The probable answer is that these textures represent different stages in the history of the microcline. For example, the plagioclase insets do not usually show the development of myrmekite; this is normally a marginal effect and always occurs in microcline embayments, therefore post-dating its formation. The clear albitic rims usually occur around insets but are rarely seen on external contacts between plagioclase and microcline and so this must be a syn-microclinisation texture. Further, the rim is always clear, not sericitised as the plagioclase host may be, nor is it twinned like the plagioclase host; therefore it must be a reactive product between microcline and plagioclase. A possible reaction to form albite would be migration of Na^+ from the plagioclase into the microcline and release of K^+ ie, a localised exchange reaction with the anorthite component, resulting in decalcification of plagioclase. (Marmo (1971, p 158) proposed the following possible reaction for the decalcification of plagioclase:- anorthite + potash feldspar + aluminium hydroxide $\rightarrow$ epidote + muscovite + quartz. The albite component would be non-reactive and the rims to the plagioclase insets may represent the front of the above reaction. Essentially, this is sassuritisation and, although the presence of epidote has not been positively identified in the sericitic groundmass of the altered insets, its presence as submicroscopic grains cannot be ruled out. Microscopic epidote inclusions in plagioclase porphyroblasts have been noted in this group and indicate that the reaction is a possibly, not to be discounted. The albitic rim can possibly be explained as an ion exchange phenomenon with release of K^+ .

The myrmekite rims are a post-microclinisation feature for which a metasomatic derivation is favoured. They formed in the waning metasomatic phase because they are only developed on the K-feldspar margins, but lack of data makes it impossible to quantify.

The following origins of myrmekite have been considered by Spry (1969):

1. Simultaneous crystallisation of crushed quartz and feldspar following marginal cataclasis.
2. Replacement of K-feldspar by quartz and acid plagioclase.
3. Exsolution of albite from K-feldspar. According to Spry (1969) the irregular distribution and proportion of quartz does not favour this explanation.

The second mechanism conforms to the original interpretation of Becke (1908) who said that myrmekite is produced by the replacement of K-feldspar by plagioclase. Lobate or 'cauliflower' myrmekites growing into K-feldspar on K-feldspar-plagioclase interfaces are a common occurrence in the Mwila Gneiss Group and is essentially a metasomatic reaction. However, Becke's interpretation conflicts with petrographic evidence in the Chisomo Area, where textures indicate that the microcline was later than the plagioclase. Drescher-Kaden (1948) was also of the opinion that myrmekite was formed with the introduction of younger microcline. A possible reaction sequence is (Orville 1962) viz:



Orville (1962, p 313) said that 'the predominance of sodium, potassium, and to a lesser extent, calcium, in fluid inclusions is a reflection of the importance of exchange equilibria involving feldspar.' To generate the above reaction at a reactive grain boundary, the plagioclase must

contain some anorthite component. Since in the Chisomo Area textures indicate replacement of plagioclase by microcline some form of ion exchange reaction may have operated with migration of Na^+ and Ca^{2+} from the plagioclase, the calcium ions reacting with the K-feldspar according to the above reaction. The observations of Becke (1908) that the proportion of quartz intergrown with plagioclase increases with increasing anorthite content of the reacting plagioclase are consistent with the above reaction.

Summarising, the following events led to the development of the granitic texture in the Nkondo Group.

- | | | |
|--|---|---------------|
| 1. Plagioclase blastesis |) | |
| |) | |
| 2. Sericitisation |) | |
| |) | |
| 3. Growth of oriented muscovite in plagioclase |) | SM_1 |
| |) | |
| 4. Microcline growth on plagioclase |) | |
| |) | |
| 5. Formation of myrmekite |) | |
| |) | |
| 6. Development of the quartz-ribbon texture |) | D_2 |
| |) | |
| 7. Polygonisation of granulite texture |) | |
| |) | MP_2 |
| 8. Quartz-ribbons replaced by microcline |) | |

The metasomatism began with event (2) and reached a peak at event (4).

The above sequence does not imply eight isolated events, but it can be shown that these stages all occurred during the development of the texture.

3.1.2. Enclaves

Two main type of enclaves are common in the Nkondo Group, fine-grained quartzites and grey, fine-grained, biotite-psammities. Amphibolites are also found, mainly in the Mwila River area.

3.1.2.1. Quartzite Enclaves

Quartzite enclaves occur in well-defined areas adjacent to the main outcrop of the Lubo Quartzite and more commonly, within the main gneiss body.

To the southwest and southeast of Lubo Hill, banded quartzite enclaves are common. They are generally less than 1 metre in length, though some larger examples are present, and subrounded to subangular in outline although aligned with their long axes in the schistosity (eg, Plate 14), and show near alignment of internal quartzite banding and external schistosity. In outcrop the more massive enclaves appear to be unaltered. Further examples of quartzite enclaves are shown in Plates 29 and 30. In Plate 29, a long subangular, banded quartzite enclave shows the coplanar relationship between quartzite banding and gneissic foliation; the absence of K-feldspar porphyroblastesis in the enclaves is characteristic. Plate 30 illustrates an enclave showing subrounded form, and also parallelism with the smaller enclave to the right; the banding in the enclaves is concordant. There appears to have been no gross rotation of enclaves relative to each other in the same outcrop, an indication of the passive formation of the enclosing granitic gneiss. Plate 30 also shows a post-enclave aplitic vein which cuts the enclave and is non-dilational. Such veins must be related to the formation of microcline in the gneiss ground-mass which shows the same aplitic texture.

In thin sections the interior of the enclaves show very well preserved metasedimentary textures and replacement (granitisation) processes are not far advanced. This is understandable as quartzites are very resistant to granitisation, as pointed out by Read (1948). The enclave margins, however, show a different picture and replacement processes are

demonstrable. In Plate 31, an irregular microcline may be seen in a quartzite groundmass, apparently favourably developed along quartz grain boundaries. Again, in Plate 33, the microcline has a skeletal appearance with growth along quartz grain boundaries and inclusion of quartz in the growing microcline. In Plate 34, the microcline has partially replaced a quartz grain, but the relic maintains optical continuity with the parent quartz outside the microcline. This example also shows microcline replacing the biotite foliation. In Plate 35, the contact relations between a quartzite enclave and the surrounding gneiss are illustrated. Here, the quartzite remained as a rigid block during D_2 and the gneiss at the contact was cataclased. The microcline has partly replaced the quartzite along grain boundaries and cracks.

Plate 32 illustrates a rare example of plagioclase blastesis. Evidence comes from the irregular line of quartz inclusions which show optical continuity with the external quartz. Typical embayed, blastic grown margins are also illustrated and microcline replacing the plagioclase can be seen to the right of the plate.

The quartzite enclaves show a textural genesis similar to the enclosing Nkondo Group gneisses.

3.1.2.2. Psammitic Enclaves

These are the commonest enclave type and occur throughout the outcrop of the Nkondo Group. They are fine-grained and lithologically very similar to the Biotite Schist Group of the Milolo Supergroup.

The psammitic enclaves are much more variable in shape than the quartzite enclaves, ranging from spherical, Plate 36, to lenticular and tabular

Plate 37. Their long axes are always aligned in the foliation of the enclosing gneiss. In Plate 36, the irregular and corroded shape of the enclave would suggest that it has been partly replaced; a thin feldspathic vein originating from the gneiss cuts the enclave. A further example of veining is shown in Plate 37. Here, no displacement of the enclave on either side of the vein has taken place, it is non-dilational and therefore metasomatic in origin. The Porphyroblasts of K-feldspar form augen in the foliation and a similar relationship is shown by the enclave, which appears to have behaved as a rigid body around which the D_2 -foliation deformed. The aplitic vein shows offshoots into this foliation and along the enclave margin suggesting emplacement-post D_2 but the vein itself is foliated by the augen containing schistosity, so the offshoots may either have been remobilised from the vein into the foliation or be following an earlier foliation and be related to a post- D_1 metasomatic event. This will be considered further in the discussion of the Mwila Gneiss Group.

Petrographically the psammitic enclaves illustrate the features already described for the Nkondo Group. Plagioclase blastesis is illustrated by Plate 39 and the inclusion of the biotite foliation indicates that this process continued locally after D_1 . In Plate 38, microcline has replaced the earlier-formed plagioclase, which is sericitised. The microcline is therefore later than the plagioclase, which fits in with the petrogenetic scheme already deduced for the Nkondo Group: that the microcline is introduced from the Nkondo Group is evidenced by the post-enclave aplitic veins originating from the gneiss which appear to be undergoing transformation to Nkondo Group type lithology. Again their quartz-rich nature has probably precluded their total assimilation. A stage in the transformation is represented by the common ghost-like relics, generally distinguished from the enclosing gneiss by their finer grain size.

In Plate 40, two enclaves showing concordance of banding and separated by a narrow layer of gneiss suggest in this case that this replacement process has occurred preferentially along banding. This preference for alteration along banding is also illustrated by the aplitic vein, which cuts the enclave and sends offshoots into the banding.

3.1.2.3 The Origin of the Enclaves

Evidence pointing to a tectonic origin is totally lacking. Using psammitic banding and quartz layering as criteria, it has been shown that there is no gross rotation of enclaves relative to each other and boudinage and its associated structures are completely absent. A palimpsest origin is therefore favoured.

The enclaves, both quartzite and psammite types, are considered to be relics of a former, more continuous metasedimentary layer. The quartzites show a distinct relationship to the main outcrop of the Lubo Quartzite, and there is an increase in the number of enclaves near major quartzite bands. Furthermore, the surrounding Nkondo Group is usually plagioclase-poor, indicating derivation from a quartz-rich source.

The psammitic enclaves show no regular spacial distribution pattern and cannot be related to any particular unit of the Biotite Schist Group. It is interesting to note however that quartz-rich psammitic types which show the textural features characteristic of the Nkondo Group, albeit on a much smaller scale, predominate. Replacement of the psammite groundmass by microcline produces a rock of Nkondo Group type and it is concluded that these enclaves represent relics of original metasedimentary bands which were plagioclase-poor and did not develop plagioclase blastesis to the extent of the Nkondo Group, thus resulting in an initial grain size

variation between the enclaves and the surrounding gneisses. The psammitic enclaves are therefore considered to be palimpsest structures.

3.1.3 Amphibolite Dykes

These rocks are melanocratic, fine-grained, hornblende-plagioclase amphibolites and are particularly well-developed in the Mwila Stream. They are preferentially eroded by streams which may follow them for distances of up to 2 km. The contact with porphyroblastic gneiss appears to be sharp, but the gneiss adjacent to the contact shows hornblende as an essential constituent, not usually found in the main group. Plate 41 shows a contact between Nkondo Group gneiss and an amphibolite dyke. Incipient K-feldspar growth is developing in the dyke and a feldspar-rich vein originating from the gneiss replaces the amphibolite along a prominent foliation. In Plate 42, the conversion of amphibolite to hornblende gneiss has produced an apparent enclave of gneiss in the dyke. The basal contact is irregular and the dyke is cut by a network of veins from the gneiss. In Plate 43, a quartzite enclave is preserved in the hornblende gneiss indicating that the amphibolites intruded the metasediments of the Mililo Supergroup and were then subsequently converted to hornblende gneiss. Plate 44 shows a common outcrop feature of these hornblende gneisses, abundant elliptical amphibolite enclaves preserved as ghost-like relic bodies.

The age of the amphibolites is post-metasediments and pre-D₁, the latter fact deduced from the occurrence of F₂-folds of an early schistosity in the dykes.

3.2 THE MWILA GNEISS GROUP

These rocks form a distinctive group of pink, fine to medium grained microcline-plagioclase-biotite gneisses of aplitic appearance. Microcline forms porphyroblasts rarely exceeding 5 mm in size. Two main areas of outcrop may be recognised. The first is an irregular-shaped body trending northeast from near the southwest corner of the area and containing the outcrop of the main calc-silicate horizon and the Mwila Gneissose Granite. To the northeast it interfingers with thin quartzite horizons of the Lubo Quartzite and the irregular contact with the Nkondo Group south of the Mwila River suggests D_3 -folding. To the northwest, where sheets of Mwila Gneiss cut into the Nkondo Group, a contact shows both concordance and discordance with the main northeast foliation. Within the Nkondo Group and near the Mwila Gneiss Group bands, aplitic lenses and veins appear.

The contact with the Lubo Quartzite is apparently sharp at TV 600869 but, south of the main quartzite, feldspathised quartz-muscovite schists and narrow quartzite bands (TV 625875) lie within the Mwila Gneiss Group.

In the central part of the outcrop, the characteristic light red to pink, fine or medium grained, granitic gneisses pass into a coarser grained rock which is pegmatitic in patches. This latter rock is the Mwila Gneissose Granite and has been separated from the Mwila Gneiss Group on the basis of grain size and texture. The outcrop is an irregular oval outline elongated north-northeast - south-southwest and characterised on air photographs by a distinctly lighter tone coupled with greater relief. Sharp contacts are lacking and a gradual transition into the Mwila Gneiss Group is noted in the field. Feldspathised biotite psammite enclaves

occur on the northeastern margin of this body, near an extension of the Lubo Quartzite.

The detailed contact relations between the Nkondo Group and the Mwila Gneiss Group have already been described in the previous section. They suggest intrusion of the Mwila Gneiss Group pre- D_2 . To the south, the rocks become more pegmatitic with metasedimentary quartz-muscovite schist enclaves and grade into the Chibambila Group (p 81).

The second main area of Mwila Gneiss Group is associated with the Migmatite Gneiss Group. Here, contacts are not exposed and the two groups seem to interdigitate and become intimately associated. However, statistical tests have shown significant differences in rock chemistry, confirming that two groups are present (see Fig 5).

In outcrop the main structural features are a prominent quartz rodding lineation, associated in some places with a mesoscopic 2-3 mm banding or quartz layering, indicating that the textural features are D_2 in age and that the Mwila Gneiss Group is pre- D_2 . The gneissose Mwila Granite outcrop may represent the effects of diapiric uplift rather than intrusion pre- D_2 .

3.2.1 Petrography of the Mwila Gneiss Group

Rocks of the Mwila Gneiss Group are fine to medium grained, light pink to pink granite gneisses. Biotite and muscovite locally up to 50% of total micas, define a schistosity. Quartz ribbons up to 2 mm wide occur parallel planar to the mica schistosity. The general aspect of the rocks is aplitic, but they are coarser in the outcrop of the Mwila Granite Gneiss where the texture is more granitic. Microcline forms porphyroblasts rarely exceeding 5 mm in size which are considered to have developed

before the dominant schistosity as they form augen.

The other main petrographic features of this group are the fine grain size of the micas (0.5 to 1.0 mm) and the apparent coeval development of the quartz, plagioclase, microcline groundmass mosaic. Evidence of early plagioclase blastesis is lacking and accessory minerals are rarely present except adjacent to quartzite bands where hematite pseudomorphs after magnetite are commonly developed.

Micas include biotite α , straw β , γ , olive brown or β , γ , green-brown as the dominant type forming subidioblastic flakes and defining a schistosity. Muscovite is also present and occurs as subidioblastic to xenoblastic flakes in the schistosity locally forming lenses and polygonised patches, eg 9FD 528. Muscovite is also present as secondary growth on sericite due to post-sericite recrystallisation.

Quartz shows two distinctive modes of occurrence as in the Nkondo Group. Groundmass quartz occurs in a granoblastic polygonal mosaic with plagioclase and microcline. The grain boundaries are straight or, more usually, curvilinear and grain boundaries tend to meet in triple points.

In the foliation the quartz forms either coarser grained, elongate ribbons or irregular elongate lenses. The crystals are polygranular showing strain extinction and sub-grain boundaries or mosaics with irregular, sutured lobate grain boundaries. In 9FD 539, the quartz is more irregular in shape and strain deformation is apparent; this type may be late-metasomatic quartz. The quartz lens textures are identical to the strained irregular quartz, but this identity is more or less destroyed in the ribbons. Examples of late irregular quartz replacing plagioclase and forming lobate intergrowths with the microcline porphyroblasts may also be

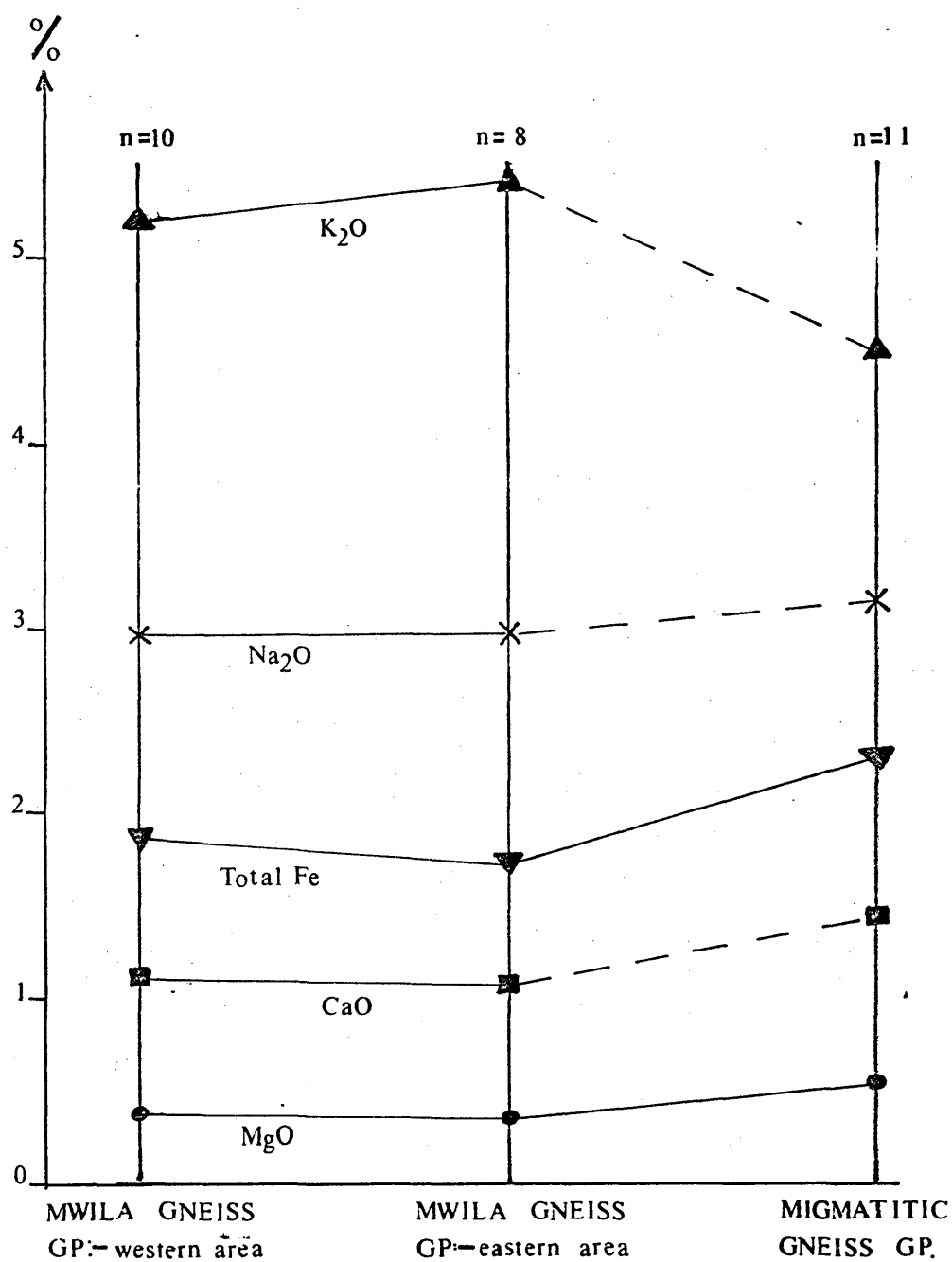


Fig 5 Comparison of mean, major oxide percentages for the Mwila Gneiss Group and the Migmatitic Gneiss Group. Student's t-test shows that at the 95% confidence level there are significant variations (dashed lines) in alkalis between the two groups. There are less than 5 in 100 chances of these two groups coming from the same population.

metasomatic graphic type growths.

Microcline has two distinct modes of occurrence. In the groundmass mosaic it forms a granoblastic polygonal aggregate with quartz and plagioclase. Grain boundaries tend to be curvilinear and meet in triple points. There is no evidence of strain extinction nor of the development of a sericitic foliation from feldspars, characteristic of cataclased granitic rocks (Harker 1932). Commonly the grains occur in aplitic patches and discontinuous lenses very similar to those described for the Nkondo Group. This groundmass texture may represent a recrystallised original aplitic mosaic.

The second recognisable type of microcline occurs as porphyroblasts and is demonstrably younger than the groundmass mosaic. All stages from skeletal growth to porphyroblasts are present. The more skeletal crystals replace the quartz mosaic along grain boundaries and include quartz grains so producing the characteristic drop-like quartz texture (Plates 45 and 46). The microcline porphyroblasts are xenoblastic to subidioblastic and seem to be later than the groundmass microcline, eg 9FD 590. The final stage of this second generation microcline growth is represented by porphyroblasts up to 10 mm in size. They predate the schistosity and the biotite-quartz foliation curves around the porphyroblasts and is polygonised (Plate 47). Later, local remobilisation into the quartz-ribbons and lenses along grain boundaries has occurred. A particularly striking example is shown by 9FD 786 where a strained, rounded quartz is enclosed in unstrained microcline.

The porphyroblasts show lobate boundaries and microcline penetrates from the porphyroblasts into the quartz mosaic. A region of strain shadow polygonised quartz which shows these replacement textures is often

associated with the pre-schistosity porphyroblasts. This is interpreted as strain induced migration of microcline from the porphyroblast into the strain shadow, an area of relatively low strain, during deformation. This effect may account for the presence of the elongate microclines so often encountered in rocks showing strong ribbon textures. Durnley (1972) also explained augen development by a similar mechanism.

As with the Nkondo Group, evidence of metasomatic blastesis comes from the occurrence of drop-like quartz inclusions and plagioclase insets in the porphyroblasts (Plates 48 and 49). The plagioclase insets show sericitised cores surrounded by clear rims in contact with the microcline. Marginal myrmekitic intergrowths against plagioclase are usually developed. The significance of these two textures was noted in the discussion of the Nkondo Group. In Plate 50, the replacement of plagioclase by microcline is demonstrated. However, it is notable that the groundmass microcline with regular grain boundaries against plagioclase does not show this texture, but, as in 9FD 570, the granoblastic microcline mosaic is incorporated into a growing porphyroblast. Late alteration of microcline to muscovite is illustrated by Plate 50. To summarise, the following stages of microcline history may be recognised:

- 1) Development of microcline-plagioclase-quartz aplitic texture.
- 2) Replacement of quartz and plagioclase by a second generation of microcline, producing plagioclase insets and drop-like quartz inclusions. Local inclusion of groundmass microcline can also be demonstrated. The inclusions form discrete grains in the microcline porphyroblast host in optical discontinuity.
- 3) Development of augen texture D_2) and migration of microcline into strain shadows; elongate microcline

aligned in the foliation.

- 4) Replacement of the D_2 quartz-ribbons by microcline.
- 5) Development of secondary xenoblastic muscovite on microcline.

Thus, following the development of the original groundmass microcline, at least three subsequent phases of microcline growth may be distinguished and stages 3) and 4) above, may represent a continuing episode.

Plagioclase is usually seen as sub-idioblastic grains in the quartz-microcline groundmass. Crystal faces are often developed and the composition is $\simeq$ An 16 determined by the Rittman Zone Method.

Plagioclase porphyroblasts are rare and do not usually exceed 2 mm in size. Fresh plagioclase is rarely seen, saussuritisation and sericitisation are well advanced and secondary crystallographically oriented muscovite is present along with granular epidote. Myrmekitisation of plagioclase is also well advanced and examples of this texture affecting the sericitised cores of plagioclase insets have been noted, eg 9FD 786. In this example no myrmekite rods pass into the clear rim surrounding the sericitic core. Evidence of blastesis from the porphyroblasts is rarely seen and this does not appear to have been a major factor in the development of the overall texture of the Mwila Gneiss Group.

3.2.2 Petrography of the Gneissose Mwila Granite

Petrographically this sub-group is very similar to the surrounding Mwila Gneiss Group. The most outstanding feature is the coarse grain size. The quartz-ribbon is usually well-developed and the irregular, lobate, coarse-grained quartz generation of possible metasomatic origin

is also present. The irregular quartz inclusions seen in plagioclase from 9FD 587 may be of this generation and replace plagioclase. A blastic origin may be discounted as the quartz lacks the typical rounded drop-like form, it being more lobate and irregular. Plates 51 to 54 illustrate features typical of these rocks which have already been described for the Mwila Gneiss Group.

It might be suggested that the Gneissosé Mwila Granite is a coarse grained mass which has survived the cataclasis that affected the Mwila Gneiss Group. However, the development of the D_2 -ribbon texture in this group argues against this as does Fig 2 which shows continuous S_2 -schistosity through the mass with no apparent deflection as would be expected from a resistant mass. Both groups seem to have identical tectonic histories. The grain size difference may be interpreted as a relict pre- D_2 feature. It could represent an original mass which has deformed into tectonic concordance.

3.2.3 Microclinisation of associated metasediments Quartzites and calc-silicate bands are locally well preserved in the Mwila Gneiss Group.

3.2.3.1 Quartzites

These rocks occur as lenses and bands within the Mwila Gneiss Group especially adjacent to the outcrop of the Lubo Quartzite and concordant with it. The surrounding granitic gneisses contain hematite pseudomorphs after magnetite, minerals not usually developed in the main body of the gneiss. The hematite must be a relic in the gneiss remaining from the original feldspathisation of a magnetite or hematite quartzite; it is a mineralogical enclave. An example is 9FD 823 which shows an inequigranular mosaic of quartz, plagioclase and microcline. The quartz morphology is comparable with that in a typical muscovite quartzite from the Lubo Quartzite Group, the groundmass granoblastic polygonal mosaics

of the Mwila Gneiss Group are absent and opaque mineral and accessory apatite are also present. In another example, 9FD 552, which can be traced along strike into the Lubo Quartzite, trains of opaque minerals defining banding are recognisable and are considered to represent an original mineral banding inherited from the quartzite. Again, in this example, zircon, apatite and tourmaline minerals which are rarely recognised in typical Mwila Gneiss Group rocks, are accessories; they must be mineral enclaves from the original quartzite. Plate 54 illustrates quartz mosaic feldspathisation.

3.2.3.2. Calc-Silicates

These rocks have already been described in detail in Section 2.3. Samples collected from the margins of the main calc-silicate body within the Mwila Gneiss Group show various replacement phenomena. Spinel, a mineral typically associated with calc-silicate parageneses, is corroded and enclosed by microcline which also includes the quartz groundmass. Epidote and amphibole are also replaced by microcline. The process seems to end with the development of narrow aplitic veins parallel to the mineral layering in the calc-silicates.

3.2.4 Petrogenesis of the Mwila Gneiss Group

Texturally the Mwila Gneiss Group is made up of a pre-Tumbide mosaic of quartz, plagioclase and microcline and metasomatism of this mosaic has led to the development of microcline porphyroblasts. Subsequent Tumbide, D_2 -movements have produced a typical blastomylonitic texture with the schistosity and quartz ribbons curving around the porphyroblasts. Some migration of microcline has occurred from the porphyroblasts into their strain shadow regions.

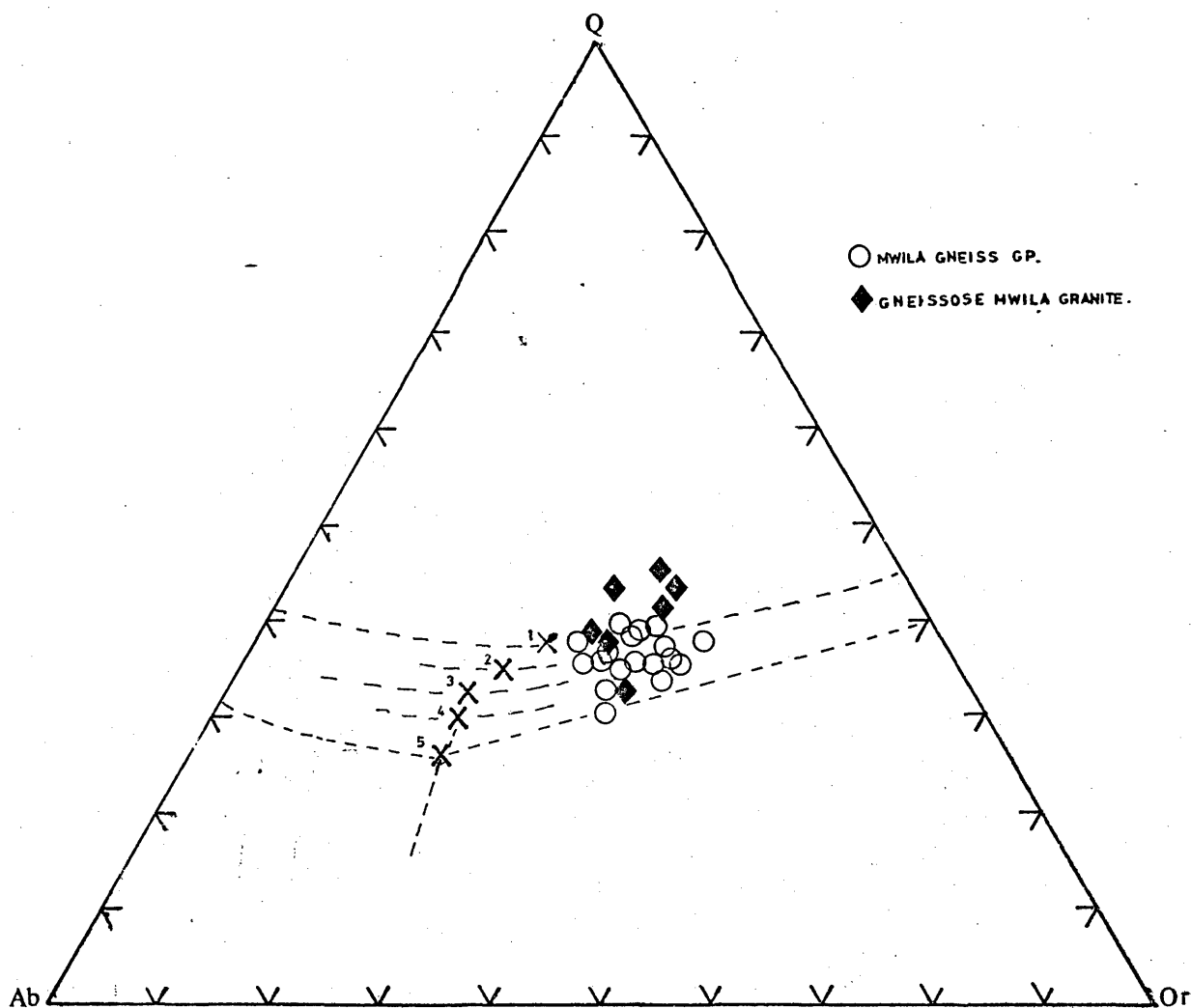


Fig6 Normative percentages of albite, orthoclase and quartz plotted onto the anhydrous base of the tetrahedron Q-Ab-Or-H₂O, the synthetic granite system. The effect of water vapour pressure on the isobaric minimum, X₁₃, and the ternary eutectic, X₄₅, is shown.

Analyses of specimens from this group show compositions lying very closely to that of a minimum melt in the system Q-Ab-Or (Fig 6 after Tuttle and Bowen (1958) and Luth et al (1964)). No significant overall composition difference is detectable between the Mwila Gneiss Group and the Gneissose Mwila Granite; all the analyses plot in a tight field near the centre of the diagram and away from the isobaric minimum. (Fig 6). A possible interpretation of this is based on the recognition of the second generation of microcline which forms porphyroblasts. If an original granite formed at an isobaric minimum, here represented by the fine grained aplitic mosaic, and was then subsequently metasomatised, it is reasonable to suppose that it would be K-feldspar-rich relative to the original minimum-melting composition. Luth et al (1964) noted from much published data that the sub-solvus granites of Tuttle (1952) contain normative corundum, a feature shown by the Mwila Gneiss Group. According to Luth et al (1964) the subsolvus granites formed under water saturated conditions and the removal of alkalis in the fluid phase would account for saturation in alumina. This is not an infallible criterion for the recognition of sub-solvus granites as pointed out by Luth et al (1964) since the melting of sedimentary material is an obvious alternative for producing alumina oversaturated rocks.

Intrusive field relationships of the Mwila Gneiss Group suggest that at some point in its history it was a melt. The presence of calc-silicates and quartzites may be explained as resisters (Read 1948). Their apparent concordance with the main metasedimentary horizons may be explained in two ways. Either they represent relics of a metasomatically transformed metasediment or the emplacement of the Mwila Gneiss Group was essentially passive into the metasediments. Pitcher (1970) in a review of ghost stratigraphy said that evidence of metasomatic origin for the enclosing granitic rock is inconclusive unless progressive

metasomatism and transformation can be firmly demonstrated although Read (1957) and Raguin (1965) both favoured metasomatic origins for all such rocks. The fact that metasomatic replacement has been demonstrated in both quartzites and calc-silicates of the Chisomo area strongly suggests that metasomatism was operative accompanied by marked intrusive behaviour. The Mwila Gneiss Group may be viewed therefore as originating by melting and intrusion followed by metasomatism of metasediments. The Gneissose Mwila Granite may represent the locus of some domal uprise similar to models demonstrated by Ramberg (1970). The actual intrusive mechanism will be discussed further in section 4.3.

Cann (1970) showed theoretically that the negative pressure-temperature slope of the wet melting curve of granite sets limits on the degree of upward movement of a wet melt. He concluded that only a dry granite magma can be erupted as a fluid. Harris et al (1970) reached similar theoretical conclusions, and their argument offers an explanation for metasomatism associated with intrusion and solidification. Assuming that magmas are at or below their liquidus temperatures, water exsolution during ascent must be accompanied by crystallisation. Since increasing pressure favours solution of water in magma, the reverse occurs with decrease in pressure, ie upward movement of magma. Upon reaching the saturated solidus the magma would crystallise while exsolved water would be responsible for metasomatism in the intrusion envelope. Since the Mwila Gneiss Group shows no chilled edges against the country rock, it is assumed to have intruded into the M_1 -amphibolite facies regime as a wet melt and no great upward movement is inferred. Furthermore, it must have derived from an original metasedimentary pile by palingenesis, and the presence of normative corundum would support this idea, rather than from towards the base of the crust which would have produced a dry

magma of the hypersolvus type. Hypersolvus granites according to Luth et al (1964, p 770) have alumina undersaturation as a characteristic. Many workers now agree that it is possible to generate granitic liquids by partial melting under amphibolite facies conditions eg, Carmichael et al (1974), Turner (1968) and Winkler (1976). Experimental investigations by Brown and Fyfe (1970) have also shown it is possible to generate silicate liquids of granite family composition under amphibolite facies conditions. The water in these experiments was derived from the breakdown of muscovite and biotite in the reaction vessel.

In conclusion, the Mwila Gneiss Group is considered by the author as a palingenetic granite formed as a wet melt under amphibolite facies conditions of metamorphism. No great upward rise of magma is envisaged.

3.3 THE MIGMATITIC GNEISS GROUP*

Dietrich and Mehnert (1960) defined migmatite as a megascopically composite rock consisting of two or more petrographically different parts: one is the country rock in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic or generally plutonic appearance. With increasing mobilisation (here used as a petrogenetically neutral term to indicate formation of minerals in pre-existing rocks by geochemical migration of mobile components such as alkalis + silica, eg in melts, solutions or gases, Mehnert (1968, p 356)), the following transitional types are recognised: schlieric, nebulitic and finally homaphanous gneisses. It is these transitional types which constitute the major part of the Migmatitic Gneiss Group. According to Carmichael et al (1974) there is now fairly general agreement amongst petrologists that partial or incomplete fusion of rocks to yield anatectic granitic melts, relative displacement (flow) of melt with respect to solid material and diffusion of ions, especially K^+ and Na^+ facilitated by a pervasive intergranular film, are all physical processes involved in the generation of migmatites.

* See Appendix 4 for glossary of migmatite terminology used in this thesis.

Petrographic observation has shown the Group to be derived by a process of granitisation of original metasedimentary rocks, the term being used in the sense of Mehnert (1968, p 354) to denote a process involving the addition or removal of rock components by means of which pre-existing solid rocks of any composition and origin are transformed into granite or granitic rocks. This is also essentially the definition of granitisation as set down by Read (1944). It will be shown in the following discussion that the granitisation in the migmatitic gneisses was essentially achieved by blastesis and the metasomatic introduction of microcline.

The geological map, Fig 2, shows that the outcrop of the Migmatitic Gneiss Group occupies the eastern section of the area. The main body is a northeast-trending, elliptical outcrop bounded on the west by the Nkondo Group and on the southeast by the Mwila Gneiss Group. A narrow elongate strip in the southeast corner is in contact with the Nkondo Group and shows an undefined, transitional junction with the Mwila Gneiss Group.

Air photographs of the eastern part of the area show a rugged, dissected zone with a light tone corresponding to the main outcrop. The presence of homogeneous, granitic gneiss types has a strong control on the drainage pattern and they form northeast-trending ridges bounded by small streams which drain to the northeast and southwest. Minor streams, draining to the southeast, coupled with the main drainage pattern show these rocks to form a topographic dome. This feature is structurally controlled and represents a major F_3 -antiformal, hinge zone (Fig 4).

On a mesoscopic or outcrop scale, the gneisses of this group are apparently homogeneous. On a larger scale broad, diffuse inhomogeneities are apparent and the following main types are recognisable.

3.3.1 Schlieric Granitic Gneisses

The schlieren, irregular streaks or masses with blended outlines (Mehnert 1968, p 356) (Plate 61), are made up of concentrations of biotite. A foliation is defined by these schlieren which is parallel to the northeast-southwest structural trend. Their formation is seen as a partial homogenisation of an original stromatic banded or veined migmatite structure due to mobilisation, a process that indicates the onset of diatexis. In the area there are numerous examples of relic, stromatic banded structures in which leucosomes are still visible. The similarity between these stromatic structures and those of the Nkonsolo Group is noticeable.

3.3.2 Nebulites

With progressive mobilisation the schlieric structure becomes more diffuse and cloudy and heterogeneities are only apparent on the outcrop scale. Sederholm (1923) applied the name nebulite to this rock type. The palaeosome and the neosome can no longer be differentiated and, in hand specimen, the rocks are igneous in appearance.

3.3.3 Homaphanites

These are homogeneous, structureless rocks representing the last stage of mobilisation. They display an even-grained, granular texture, in outcrop, with idiomorphic plagioclase crystals weathering

out. Sederholm (1923) proposed the term homophanous to designate a non-schistose massive nature. Although the rocks from this area are foliated, the term is retained because petrographic observation indicates that the foliation post-dates their formation thus these rocks are now gneissose, homaphanous, migmatitic granites.

3.3.4 Enclaves

The term migmatitic is retained in the name of the group because the abundant metatexite enclaves point to its origin. Two main enclave types may be recognised, those of definite metasedimentary origin such as quartzite, associated biotite schists and calc silicates, and other lithologies which cannot be assigned to a particular variety of metasediment and, according to Didier (1973, p 325), are characteristic of migmatitic granites. This latter enclave type is characterised by the surmicaceous enclaves (Didier, 1973, p 303) and biotite-plagioclase gneiss enclaves with a biotite-rich rim, ie restites.

3.3.4.1 Metasedimentary Enclaves

Plate 55 shows typical metasedimentary enclaves in a diatexite gneiss. The quartzite represents a once more continuous lithological band and there is contact with a relict psammitic intercalation. A disrupted psammitic enclave is in contact with a nebulous leucocratic layer which may represent the original quartzite. Further evidence of the active replacement of resistant enclaves is shown in Plate 56. Here a banded quartzite band shows granitisation along banding. Relict conformable banding and schlieren continuous with the quartzite banding in the diatexite are strong evidence that replacement processes have operated in a solid medium. In Plate 55, the biotite schist bands

show leucosome development and indicate that metatexis operated prior to their inclusion in the surrounding diatexite.

3.3.4.2 Restite Enclaves

The surmicaceous enclaves are composed essentially of biotite and are generally oval in shape, with coarse grained, generally mesoscopically, decussate biotite visible (Plate 57); quartz and plagioclase are minor and interstitial constituents. Due to mobilisation of the surrounding gneisses they may be drawn out into schlieren in alignment with the foliation. The genesis of such enclaves according to Didier (1973, p 6) is due to the concentration of restitic minerals during anatexis. This would seem a reasonable hypothesis and analogous to the formation of melanosomes during metatexis. Further supporting evidence comes from the consideration of the biotite-plagioclase gneiss enclaves. These are generally larger than the surmicaceous enclaves by an order of magnitude, have a flattened, ovoid form, and are aligned in the foliation. The contact with the surrounding diatexites is sharp and defined by an envelope rich in biotite. All have granoblastic textures and are often banded with biotite-rich bands alternating with quartz-feldspathic bands. Didier (1973, p 326) pointed out that the modal compositions of such rocks plot in a very small field in the Q-Bt-Plag triangular diagram. There are two possibilities - the rocks have either an original meta-sedimentary composition or are products of diatexis. A number of criteria suggest the latter interpretation of these rocks as restites (cf Mehnert, 1968, p 356); ie (1) richness in biotite; (2) the presence of drop-like quartz inclusions in the plagioclase, indicating a blastic paragenesis; and (3) the absence of this typical composition

from the surrounding metasediments and their localised field in the triangular diagram. Furthermore, in the Chisomo Area the biotite-plagioclase gneisses differ from the biotite schist palaeosome relicts in that they have not been found associated with banded quartzite.

3.3.5 Evidence of mobility of the diatexites from enclaves

Unlike the enclaves described from the Nkondo Group there are numerous instances of coexisting metasedimentary enclaves showing mutual discordance of metasedimentary banding, indicating that the diatexite host has been mobile and has destroyed any original alignments. This is evidence in favour of the para-autochthonous nature of the diatexites. Strictly they do not represent formation in situ, most of the examples of this mobility come from mesoscopic examples. Plate 58 shows an example of an interbanded quartzite-psammite sequence being intruded by diatexite; in detail (Plate 59) the conformity of banding has been destroyed. This is also apparent in Plate 55. Mobility of the diatexites is also demonstrated in the field at the contact with the Nkondo Group to the north. Many examples of porphyroblastic gneiss enclaves in the diatexites were noted indicating that, here, the diatexites are intrusive. Since the Nkondo Group enclaves show K-feldspar porphyroblasts and both the enclaves and the diatexites are foliated by the schistosity associated with the augen, a pre-D₂ intrusive age can be deduced which, however, is later than the development of microcline porphyroblasts in the Nkondo Group. The calc silicate bands to the southeast and within the diatexites show a ghost stratigraphy and suggest little or no movement. It is possible that mobilisation did occur, but ghost stratigraphy was preserved.

3.3.6 Sequence of Mobilisation

The sequence of progressive mobilisation in a migmatite terrain has been shown by Mehnert (1968, p 273) to follow the general scheme.

1. Recrystallisation and blastic growth mainly of potash feldspar and/or plagioclase.
2. Metatexis: Formation of a partial cotectic, water bearing melt of quartz and feldspar which separates from a restite enriched in the remaining mafic components, the melanosome, and forms the leucosome. Only minerals present in the original palaeosome will enter into the leucosomes.
3. Diatexis: Transformation of predominantly molten material, including the mafic components, the melanosomes, into schlieric and nebulitic rocks.
4. Homogenisation of the palingenetic melts and intrusion into the surrounding country rocks.

This progressive sequence is discussed below with special reference to the Migmatitic Gneiss Group.

3.3.6.1 Stage 1. Recrystallisation

As might be expected, evidence of this stage of mobilisation is only rarely preserved in the group because of its dominant diatexite nature.

3.3.6.2 Stage 2. Metatexis

Petrographically the associated metatexites are instructive as they

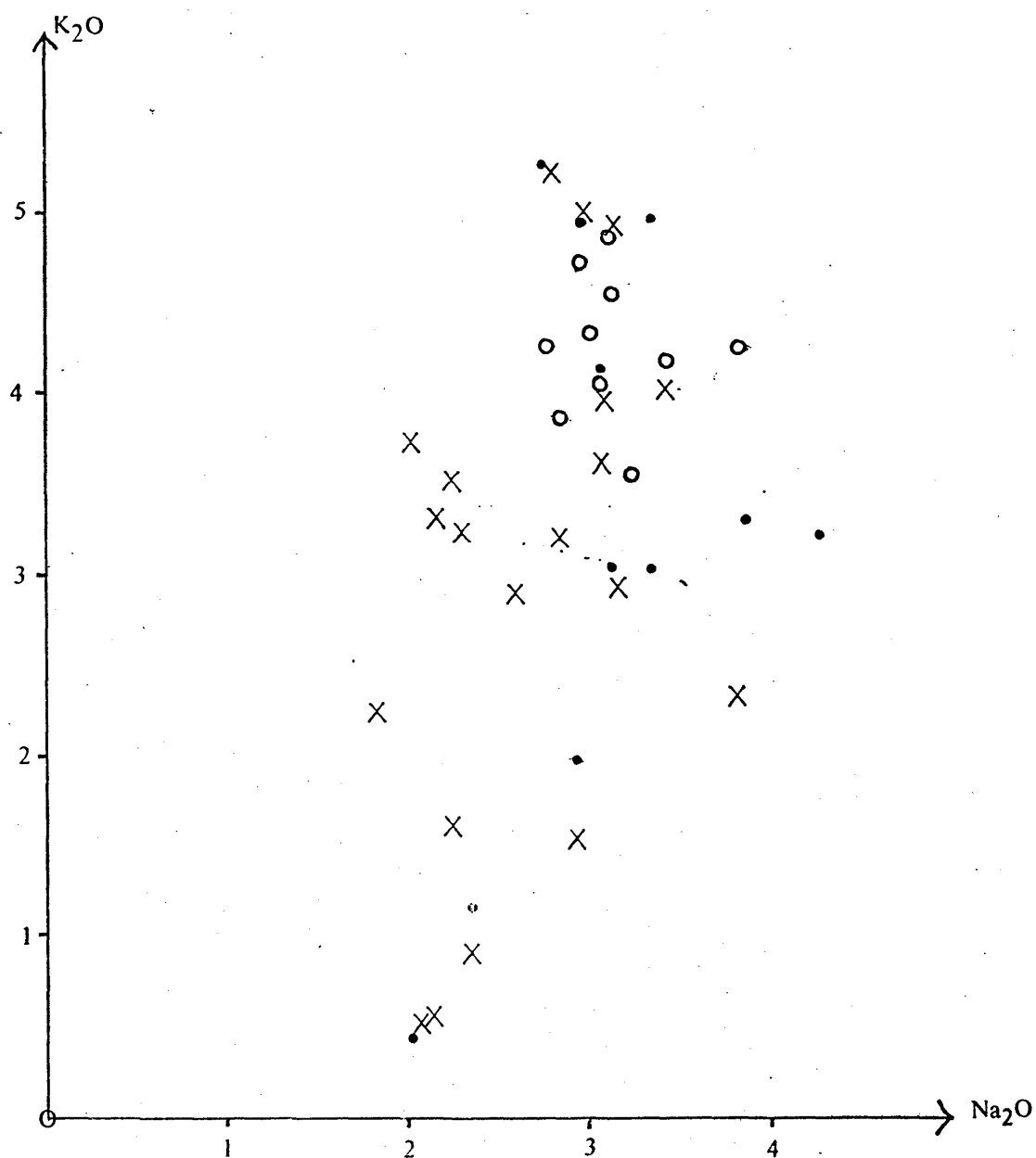


Fig.7 Variation diagram of potash against soda for metatexites (crosses), metasediments (solid circles) and some examples relatively low in potash from the Nkondo Group (open circles)

give an insight into the early recrystallisation stage. The main event appears to have been plagioclase blastesis in an original palaeosome. The textural development is the same as that already described for the Nkondo and Nkonsolo Groups. Figure 7 is a K_2O/Na_2O variation diagram for the metasediments and metatexites from the area of detailed study. Although there is a wide scatter of K_2O/Na_2O ratios it is evident that there is no marked splitting of the values into distinct fields; metatexites plot side by side with metasediments. The indications are that a blastic process would account for the increased mobilisation from stages (1) to (2) and that no addition of material need be postulated. It is interesting also that the more basic members of the Nkondo Group plot in the same general field indicating, as petrographic observation has already shown, that processes similar to metatexis operated during their genesis, in particular plagioclase blastesis.

The metatexis stage is best observed on the mesoscopic scale; the rocks take on a banded or stromatic appearance with metasediment, the palaeosome, separated from the quartzo-feldspathic leucosome by a thin biotite-rich zone, the melanosome. An unusual development of this stage is shown in Plate 60. The quartzo-feldspathic segregations form ovoids with a micaceous outer rim in a biotite-plagioclase psammite palaeosome. It has already been shown (Plate 55) that this stage is preserved in some metasedimentary enclaves.

Petrographically the leucosomes or metatects are characterised by a xenomorphic granular mosaic of quartz and plagioclase. Grain boundaries tend to be curvilinear and plagioclase is subidiomorphic with drop-like quartz inclusions indicating blastic growth; secondary twin plane

sericitisation is usual. Plate 62 shows plagioclase with idiomorphic outlines and sericitisation. Where microcline is present it is later than the plagioclase, as in Plate 62; it also replaces the quartz mosaic (Plate 63). Further, there is often a marked decrease in the size and amount of K-feldspar crystals across the melanosome into the palaeosome. These observations support the view that K-feldspar growth was later than the plagioclase blastesis and that the leucosomes offered a path of least resistance for K-feldspar mobilisation. This also favours Mehnert's (1968) idea that the leucosome was a water-bearing partial melt with the water, probably as an intergranular film, the route of subsequent introductions of potash.

The melanosome, usually 2-3 mm thick, is composed of biotite which defines a schistosity parallel to the leucosomes and to the schistosity in the palaeosome. Apatite and minor quartz are also present. Mehnert (1968, p 247) has shown that the leucosomes derived from biotite-plagioclase paragneisses of varying composition plot in a well-defined field in the $Q - \Sigma \text{feld} - \Sigma \text{maf}$ triangular diagram, the ratio of quartz to total feldspar being 30-35% vol quartz to 65-70% vol total feldspars. He concluded that the composition of the leucosomes of the paragneisses he investigated corresponded closely to their minimum melting composition. Earlier work by Mehnert (1951, 1962) quoted by Mehnert (1968, p 249) showed quantitatively that the mean values of leucosomes, parent rocks and melanosomes approximately lie on a straight line in the triangular diagram $Q - \Sigma \text{Feld} - \Sigma \text{Maf}$ and this was used as an argument in favour of the equation of palaeosome = melanosome + leucosome.

White (1966) in discussing the migmatites of the Palmer Region of South Australia also recognised the mineralogical balance described above, and, furthermore, assumed that the leucosomes developed by metamorphic segregation in an essentially closed system. He based his argument on Ba/Rb ratios of coexisting K-feldspar in the leucosome and biotite in the melanosome. If these two minerals formed by metamorphic segregation, they must have developed in equilibrium and therefore the distribution $\log a_{\text{Ba/Rb Bt}} = \log a_{\text{Ba/Rb Kfeld}} + \log K_{\text{pt}}$ should hold. K , the distribution coefficient is constant for a given pressure and temperature. White (ibid) plotted $\log \text{Ba/Rb}_{\text{Bt}}$ vs $\log \text{Ba/Rb}_{\text{Kfeld}}$ assuming ideal solution behaviour and neglecting the term a , the activity. He found the points plotted close to a straight line with a gradient of 45° , indicating that K-feldspar and biotite are in equilibrium.

It has already been noted that the rocks from the Chisomo Area show microcline as a later mineral, so that the mode of formation of the leucosomes was therefore a two stage event. The constant thickness of the leucosomes at about 10 mm would indicate that a diffusion mechanism may have operated.

The concordance of the leucosomes with the schistosity of the palaeosome is taken to indicate syn-migmatic formation of schistosity.

Plate 64 shows a well-developed F_2 -fold in metatexite which folds the leucosomes and the palaeosome banding; a pre- D_2 age is indicated for metatexis. In Plates 65 and 66, a nebulous diatexite shows an F_2 -fold with an axial planar schistosity developed and elongation of surmicaceous enclaves in the axial plane; pre- D_2 diatexis is again indicated. Since the leucosomes are folded with an earlier schistosity in the metatexites and they developed coplanar with this earlier schistosity,

formation during D_1 is postulated. It has already been shown there was a syn-kinematic metamorphism with this phase of deformation.

3.3.6.3 Stage 3. Diatexis

This is the final stage in the remobilisation of the migmatites.

In the Chisomo Area schlieric and nebulitic types predominate with abundant metatexite enclaves. The mobility and local intrusive nature of this rock type has already been described. Figure 8 shows a triangular plot of Q- Feld- Fem for the diatexites and associated metatexite enclaves. The two fields overlap and there is evidence of metatexite compositions similar to those of the diatexites. This indicates that the diatexites probably formed from the metatexites by homogenisation. Quartz-rich lithologies in the metatexites are present, since being resistors, these rocks are not so susceptible to transformation. There is a slight enrichment in K-Feld in the diatexites compared with the metatexites and Figure 9 shows that this is due mainly to an increase in K_2O . A marked decrease in CaO must be related to the introduction of K_2O . A linear trend towards the K_2O corner of the diagram away from CaO may be explained as a reaction between introduced K_2O and the anorthite component of plagioclase. The calcium may have been metasomatically released as $CaCO_3$, as there is evidence from the preceding groups of late veining of microcline by carbonate. Turner (1968) states that few would now deny that the granitic fraction of migmatites was once largely or completely fluid, and a view that receives strong support from the experimental work of Winkler (1976) who stated that at the highest temperatures of metamorphism regional anatexis and formation of migmatites is inevitable if some H_2O is present. Further, Winkler (1976) stated that formation of melts by anatexis is a process having a sound physiochemical basis.

Fig.8 Quantitative relations(normative) between diatexites (open circles) and metatexites (crosses)

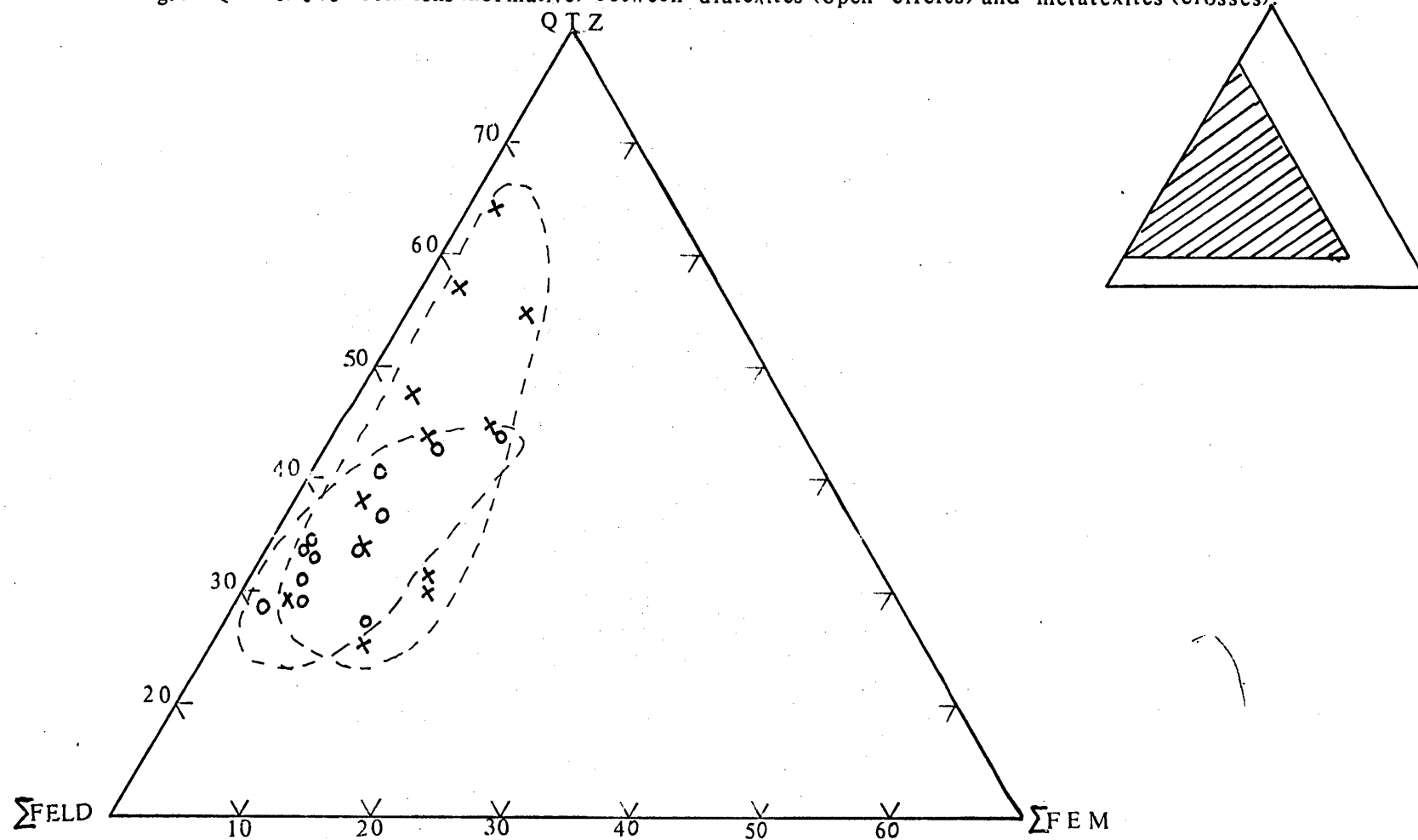
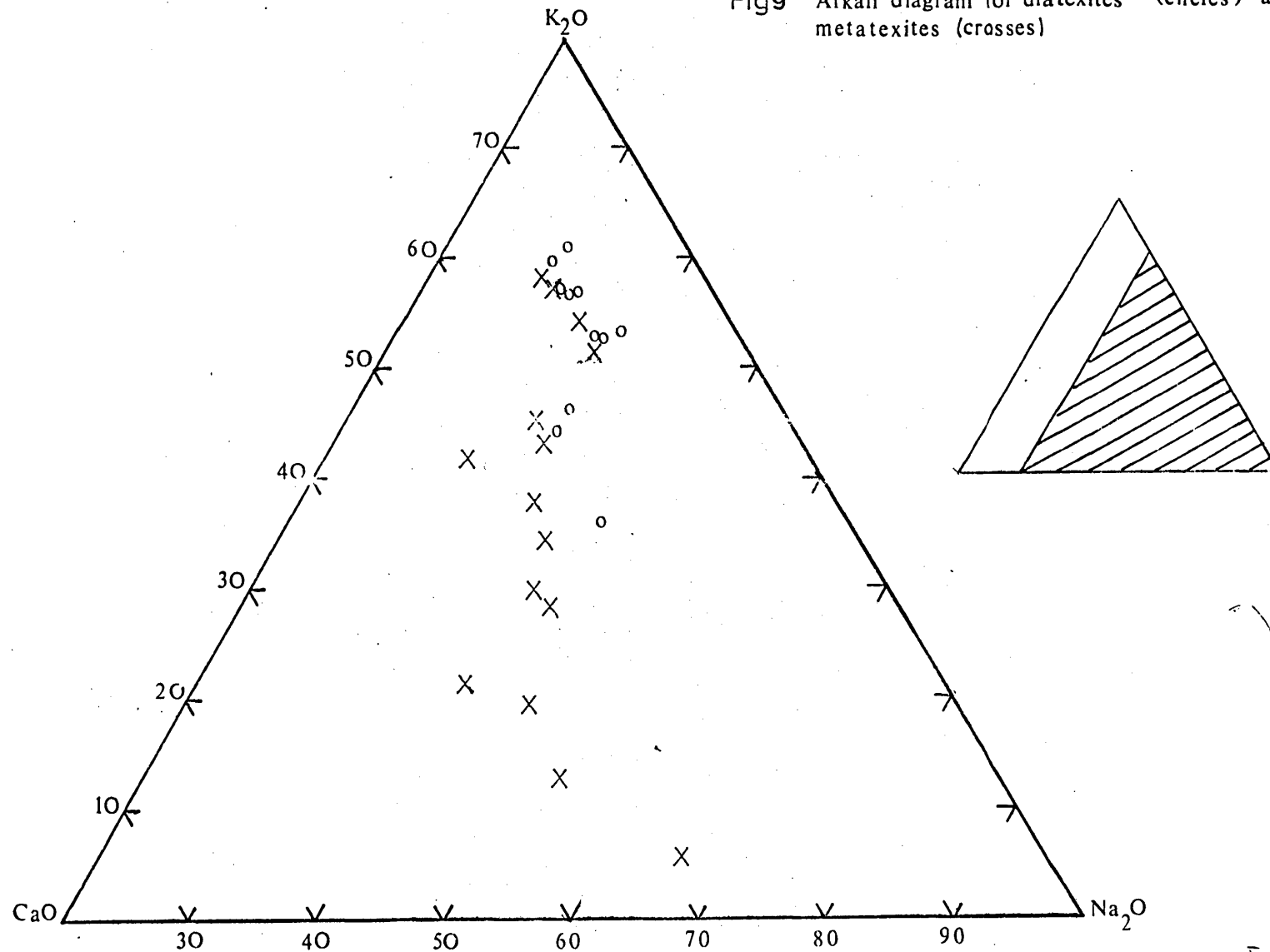


Fig9 Alkali diagram for diatexites (circles) and metatexites (crosses)



3.3.7 Examples of Mobilisation leading to the Formation of Diatexites

In the central part of the migmatite gneiss massif at TV 660845 a biotite psammite enclave grades from granitic gneiss to biotite psammite (Plate 67). The gneiss surrounding the enclave is seen to be schlieric and nebulous, an appearance caused by the presence of irregular diffuse patches of light grey, medium-grained, equigranular biotite-muscovite, granitic gneiss in leucocratic medium-grained biotite-muscovite granitic gneiss. Medium-grained granitic leucosomes are still recognisable but show diffuse borders where the melanosome has been transformed. Towards the enclave contact biotite schlieren are more common and leucosome-melanosome differentiation is possible in a partially homogenised gneiss. Enclaves of recognisable biotite psammite in this zone show feldspathisation to produce mesotypic, medium-grained, granitic gneiss. At the limit of feldspathisation a faint biotite-rich band is present.

In the above example the occurrence of relict biotite schist enclaves suggests that they were part of a banded metatexite sequence which has been transformed into schlieric diatexite. Metasomatism associated with the diatexis has feldspathised the enclaves.

At TV 650837, Plates 69 and 70, the above processes are well displayed, lenses of grey, fine-grained, banded biotite psammite showing stromatic leucosomes (Plate 69) occur in a light grey, medium-grained biotite-muscovite granitic gneiss. The leucosomes define F_2 -fold closures and there is also axial planar regrowth of biotite to F_2 -folds in the psammitic banding indicating the pre- D_2 age of metatexis.

The stromatic banded biotite psammite is exposed for a distance of 7 metres from the contact with the granitic gneisses. Near the contact it is schlieric; thin stromatic leucosomes and associated biotite-rich schlieren are still recognisable. The leucosomes pinch and swell and the palaeosome appears diffuse and nebulous due to feldspathisation. Within the diatexite gneisses, biotite psammite enclaves are preserved. Here again, the stages of mobilisation proposed by Mehnert (ibid) are well-displayed. Mehnert (1968, p 253) used the form of the schlieren as an indication of the turbulent fluid nature of the diatexites, demonstrated by the enclaves and contact relationships. The inference is that the diatexites were possibly in a molten condition and all the evidence so far put forward points to these rocks being palingenetic.

3.3.8 Petrography: Diatexites

As would be expected, transitions between blastic and igneous textures are present in this group, all modified to a certain extent by post-migmatic D_2 -tectonism and M_2 metamorphism. In thin section the difference between schlieric, nebulitic and homaphanous types is not apparent, a reflection of the mesoscopic scale of these textures. The main characteristic is the idiomorphism of plagioclase and its equant form, well displayed on weathered surfaces.

Micas consist of straw, olive-brown biotite, usually as discrete, subidioblastic flakes defining a schistosity. Local polygranular aggregates lie in the schistosity. Muscovite is xenoblastic, occurring as discrete ragged flakes and aggregates oriented in the schistosity.

These are deformed around microcline and plagioclase porphyroblasts, and show strain extinction. The schistosity is therefore later than the microcline and plagioclase porphyroblasts. Secondary muscovite after sericite occurs on plagioclase.

Quartz, in common with the preceding groups, two distinctive modes of occurrence can be recognised.

In the groundmass the quartz grains (0.2-0.5 mm) show straight grain boundaries against each other and form a granoblastic polygonal mosaic; some triple points are present in contact with microcline and the grain boundaries are irregular and rounded. Locally, however, the boundaries are diffuse and indicate a reactive site.

Relict quartz lenses and ribbons up to 1 mm thick and with a grain size of 0.5-1.0 mm are present and, although strain effects are only weak, internal sub-grain boundaries occur. The ribbons are short relicts passing into polygonal mosaics and the M_2 annealing effect is much more pronounced in this group. The higher grade of M_2 here is also reflected in the stability of the M_1 assemblage $Q + Tr + Di + Cc$ in the associated calc-silicate bands.

Plagioclase Plagioclase porphyroblasts show distinct equant idio-blastic habits (Plate 77) and there is abundant evidence of blastesis into the quartz groundmass mosaic (Plate 68). The plagioclase grows skeletally along grain boundaries.

Sericitisation and saussuritisation are usually well advanced, but all stages from patchy development (Plate 77) to almost complete mimetic replacement (Plate 73) may be seen. An example from 9FD 866 shows

biotite included in a sericitised plagioclase and is evidence of blastic growth during the first schistosity-forming event D_1 . In some examples (Plates 71 and 72), secondary metasomatic muscovite occurs in the plagioclase as crystallographically oriented inclusions.

K-feldspar Perthite and microcline are both common in this group.

The perthites generally show fine-scale thread and bead type structures (Spry 1969, p 182), more characteristic of magmatic rocks, that may be interpreted as exsolution lamellae which formed on cooling. Hair perthite porphyroblasts show rounded xenoblastic form; the contacts with groundmass quartz are generally straight to curvilinear and sharply defined. Drop-like quartz inclusions, so characteristic of microcline, are rare but an example of a plagioclase inset occurs in 9FD 866. The plagioclase shows a well-twinned core surrounded by a clear rim. This texture was considered with the Nkondo Group rocks.

Microcline forms xenoblastic, pre-schistosity porphyroblasts which are poikiloblastic with quartz and plagioclase inclusions (Plate 74). Examples of microcline-plagioclase contacts showing myrmekite in the plagioclase are present and insets show the characteristic cauliflower-like growth. Infiltration of microcline along lobate quartz grain boundaries is common and included quartz gives rise to the characteristic drops. The groundmass microcline growing across quartz-ribbons and the associated mica schistosity apparently contradict the pre-schistosity age, but may be attributed to M_2 remobilisation of microcline.

The microcline genesis post-dates plagioclase blastesis. Many examples of microcline growing on altered plagioclase may be noted (Plates 68, 71 and 73). The formation of the plagioclase insets is explained by

this replacement process and in Plate 74, insets and sericitic pigments representing relic insets may be seen.

3.3.9 Petrography: Metatexite Enclaves

In the diatexites described above, metatexite enclaves are present. It is instructive to examine these petrographically as they show the first indications of metatexis, namely blastesis. In 9FD 867, from a migmatitic, biotite psammite showing the development of stromatic leucosomes, there is a well-developed schistosity of biotite with accessory opaque minerals and rounded and abraded zircon. The interstitial quartz mosaic is distinctly poor in plagioclase. The corresponding leucocratic bands show plagioclase with rounded xenoblastic outline. Plagioclase formation occurs by skeletal outgrowth into the quartz mosaic (Plate 76) and drop-like quartz inclusions, groundmass remnants, are included. Metasomatic microcline occurs as narrow, irregular intergranular blebs which replace plagioclase along its margins.

The petrographic evidence supports the argument that diatexis was not strictly isochemical palingenesis of the metasediments. Microcline metasomatism is indicated and its effects were more pronounced in the diatexites than in the metatexites which would account for the variations shown in Figure 7. Microcline metasomatism is favoured because there is no evidence of early microcline in the original metasediments.

The last event recorded by the diatexites is the intrusion of post-diatexite pegmatitic and aplitic veins (Plate 78). These have been

dated as pre-D₂ as at TV 645799 where there is a pegmatite which is discordant to and foliated by the second deformation schistosity.

3.4 THE CHIBAMBILA GROUP

This group is very heterogeneous but is characterised by pink, coarse, light red pegmatitic gneisses with abundant metasediment bands. It was named after the Chibambila Stream which flows through the southern part of the outcrop. The group occupies a distinct belt extending northeast from the southwest corner of the area. At the northeast end of the outcrop, the form of the contact with the Mwila Gneiss Group indicates that it has been folded during D₃ while the contact with the Mwila Gneiss Group to the northwest is conformable on the dominant northeast trend.

The metasediments are mainly medium to coarsely crystalline muscovite and biotite semi-pelites, psammites and quartzites. The quartzose varieties are extensively feldspathised and the presence of microcline gives the schists a pink, granular appearance. Muscovite is usually pale greenish-grey in colour. In outcrops the scale metasediment lenses are conformable with the foliation of the gneisses and can be traced as distinct bands throughout the Chibambila Group outcrop on a northeast trend, giving rise to a distinct air photo expression. The alternating pegmatitic gneisses often form ridges.

The Group is also distinguished by a marked variation in grain size from very coarse pegmatitic gneisses through to medium-grained, granular aplitic gneisses. All the gneisses show cataclasis and the

pegmatitic varieties, especially, show well-developed mesoscopic, porphyroclastic textures (Plate 79). In thin sections the characteristic D_2 -texture defined by elongate quartz lenticles and ribbons is present and the pegmatitic gneiss therefore predates D_2 . In both the Mwila Gneiss Group and the Migmatitic Gneiss Group late pegmatite dykes have been recognised. In the Mililo Supergroup, near the Mililo Stream, pegmatitic dykes can be traced for distances of 2 km. If these dykes are related to the genesis of the Chibambila Group then clearly its formation postdates the Migmatitic Gneiss Group, the Mwila Gneiss Group and the metasediments. The dykes differ from the Chibambila Group pegmatitic gneisses in having well-defined contacts, especially in the Mililo Supergroup. The associated pelitic assemblages in the Chibambila Group show increasing feldspathisation near the pegmatitic gneisses. The metasediments become schlieric where relicts of the original metasedimentary foliation, usually defined by muscovite, are still apparent. An intermediate stage of this feldspathisation shows pegmatitic veins with diffuse, nebulous margins. The process of pegmatisation also seems to involve recrystallisation of quartz and muscovite. The end result is a medium to coarse, granular, muscovite-quartz-feldspathic gneiss which locally resembles the Mwila Gneissose Granite.

Evidence of the age of these pegmatitic dykes with sharp contacts actually comes from exposures in the Chibambila Group and consideration of the Migmatitic Gneiss Group pegmatites points to there being more than one phase present. Plate 80 shows a pegmatite dyke with sharp contacts against a diatexite gneiss. The dyke has been displaced and locally remobilised along widely spaced northeast-trending shear surfaces. The shears are D_2 in age because K-feldspars in the

3.4.1 Petrography of the Pegmatitic Gneisses

D₂-cataclasis and metasomatism of varying intensity has produced a number of differing rock types. They range from recognisably pegmatitic gneisses through granular gneisses with pegmatitic relicts into even-grained, granular gneisses. The latter rocks are similar in appearance to the Mwila Gneiss Group but tend to be slightly coarser grained.

3.4.1.1 Gneissose Pegmatites

The foliation is defined by a weak muscovite schistosity and usually a strong quartz-ribbon texture. The quartz grains are xenoblastic and elongated in the schistosity. They show strain extinction and internal sub-grain boundaries. The groundmass mosaic is a heteroblastic, granoblastic aggregate of quartz, microcline and sericitised plagioclase. The microcline shows twin plane bending and strain extinction, a feature also shown by plagioclase. Microcline porphyroblasts, up to 5 mm long, show regrowth and incorporation of quartz at the crystal margins. Inclusions of sericitised plagioclase and quartz droplets indicate a pre-cataclastic, metasomatic initial growth of microcline. 9FD 640 shows a microcline porphyroblast cut by a quartz-ribbon. The microcline contains sericitised, plagioclase insets and there is evidence of remobilisation of microcline along the grain boundaries in the quartz-ribbon. Secondary muscovite, recrystallised from sericite is seen in some samples. In some thin sections the K-feldspar is orthoclase showing hair perthite texture. In 9FD 626, a large orthoclase crystal is cut by a microplitic vein of quartz and microcline.

surrounding gneiss are also converted to augen, a characteristic D_2 -texture, and therefore pegmatite intrusion would have been pre- D_2 . Plates 81 and 82 show two examples of pegmatites from a banded, biotite-muscovite psammite lens in the Chibambila Group. In both cases the banding is buckled on northeast axes and the 1_2 lineation is deformed. These open, small-scale folds are therefore F_3 . In Plate 81, the banding can be traced across the gently folded pegmatite vein and small offshoots from the main vein are present. There is no melanosome developed adjacent to these coarse, pegmatitic veins. It will be recalled that the presence of mafic-rich layers, adjacent to granitic leucosomes, was used as a criterion for anatexis and quantitative mineralogical data have shown this to be true in the case of the Migmatitic Gneiss Group. King (1948) described non-dilational pegmatites and aplites from the Osi Area, Nigeria and proposed a metasomatic origin for them. In Plate 82, the pegmatite dyke occurs on the limb of an open F_3 -fold and approximately coplanar with the axial plane of the fold. Displacement of banding is evident, but if the two sides of the dyke are returned to their original position, assuming a simple dilation emplacement, then some displacement of banding remains. Shear parallel to the dyke margins must therefore be invoked in the sense indicated to account for the field relationships. At the top of the photograph are small non-dilational offshoots from the main dyke. A small enclave which is in the process of being incorporated into the dyke shows no evidence of disruption from the wall rock and a passive emplacement of the dyke must be invoked. In both cases the dykes may be interpreted as syn- D_3 metasomatic dykes. Field evidence suggests that there was remobilisation of this group during D_2 and D_3 leading to the emplacement of pegmatite veins and dykes in the area.

3.4.1.2 Granular Pegmatitic Gneisses

In this gneiss sub-group the foliation is well-defined by quartz lenses showing polygonised grain boundaries and little internal strain and the numerous, sub-grain boundaries of the previous sub-group have all but disappeared. Subidioblastic grains of muscovite in polygonised lenses define the schistosity. Microcline porphyroblasts set in a fine-grained granoblastic, elongate quartz-feldspar mosaic predate the schistosity, which is curved around the microcline grains. The muscovite is apparently unstrained, indicating that the metamorphism associated with the formation of these microcline augen textures was post-kinematic (M_2).

Microcline occurs as xenoblastic porphyroblasts with quartz inclusions and myrmekite embayments developed on plagioclase contacts. The marginal textures, especially those in the quartz groundmass, indicate that microcline grew into the grain boundaries. Plates 83 and 84 show microcline replacing a plagioclase porphyroblast. The microcline can be seen to be advancing along cracks and replacing plagioclase. Numerous blebs of microcline within the plagioclase host are in optical continuity.

Some examples of this gneiss sub-group, especially from the southwest corner of the outcrop, show dominant plagioclase blastesis and groundmass textures suggest derivation from a metasediment. Plate 85 is a good example of this. The groundmass is a granoblastic polygonal mosaic of plagioclase and quartz. The latter forms irregular polygranular lenses parallel to the schistosity and plagioclase forms porphyroblasts with drop-like quartz inclusions. This plate also demonstrates the replacement of plagioclase by microcline showing

optical continuity through the plagioclase. Plagioclase insets can be seen.

Plate 85 also shows the pre-schistosity nature of the plagioclase. The polygonised quartz-ribbon can be seen curving around the crystal. Blastic growth is demonstrated by the preservation of drop-like quartz inclusions within the crystal margins; the growth direction of the plagioclase is indicated by arrows. This plate also illustrates two directions of preferred orientation of muscovite flakes in the plagioclase. Similar textural features are illustrated in Plate 86. The plagioclase shows well-developed blastesis into the quartz mosaic and an irregular quartz bleb is seen inside the crystal. The muscovite inclusions are again present. The margin of the plagioclase is showing skeletal-like growth. The blastesis has been deduced to predate the quartz-ribbon foliation texture as some examples of blasts show strain extinction in bands parallel to the schistosity. The strain must have been induced during the development of the foliation.

3.4.1.3 Even-grained granular gneisses

This sub-group comprises light red granular muscovite-quartz-feldspathic gneisses, which usually occur as bands in the pegmatitic gneisses. Xenoblastic, patchily distributed muscovite defines a weak schistosity parallel with the elongated quartz mosaic. The groundmass consists of a fine-grained, partially polygonised mosaic of quartz, plagioclase and microcline. The plagioclases are heavily sericitised and are partially replaced by xenoblastic microcline, which also feldspathises the groundmass mosaic. During this process of replacement quartz inclusions

may be enclosed by growing microcline and so give rise to the characteristic drop-quartz texture. It is significant that the aplitic gneiss dykes in the metasediments of the Mililo Supergroup show very similar textures. One example, in particular, 9FD 601, shows a distinctly psammitic groundmass of quartz and plagioclase forming a granoblastic mosaic which is being replaced by later microcline. Opaque minerals, a common metasedimentary accessory are also present in this sample. Other examples from this sub-group show relict pegmatitic textures as heteroblastic mosaics of strained quartz, plagioclase and microcline and have arrived at their even-grained texture by cataclasis of an original pegmatitic gneiss.

3.4.2 Petrography of Metasediments associated with the Pegmatitic Gneisses

The metasedimentary rocks in the Chibambila Group are recognisable as grey, fine-grained and banded muscovite-biotite psammities. Their petrography indicates introduction of microcline by metasomatism. It is difficult to decide whether the muscovite-quartz schists in this group are metasedimentary or not, progressive tectono-metamorphism of pegmatite leads to a rock very similar in appearance to a feldspathised quartz-muscovite schist. In the southwest part of the outcrop, a major metasedimentary band composed of biotite-quartz psammite and muscovite-quartz schist contains coarse, pegmatitic dykes. In 9FD 583 (Plate 87) small grains of microcline occur in the quartz-plagioclase, groundmass mosaic of a muscovite-biotite psammite. Microcline has grown along quartz grain boundaries and nucleated on plagioclase. It is just possible to see a partially enclosed, myrmekitised plagioclase inset in the microcline at the centre of the plate. The large microcline at the bottom left of the plate has also

grown on altered (sericitised) plagioclase. The microcline is quite fresh.

3.4.3 Petrogenesis of the Chibambila Group

As with the preceding groups, the petrogenesis can be understood in terms of metasomatic processes. The first recognisable, significant mineralogical change is plagioclase blastesis which is particularly well-featured in the even-grained gneisses and the metasedimentary lenses. Prior to microcline growth, by metasomatism, the plagioclase was sericitised and metasomatic mica locally shows preferred orientation in the plagioclase host, but usually the sericitisation has advanced along twin planes. The microcline transforms the quartz mosaic and also replaces plagioclase. Incomplete replacement gives rise to the characteristic drop-like quartz inclusions and plagioclase insets. Myrmekite formation due to reaction between plagioclase and K-feldspar is a later event. Subsequent to microcline growth D_2 -cataclasis produced the characteristic ribbon textures, and augen. The second metamorphism, M_2 , was after D_2 and polygonised the foliation, especially noticeable where it was deformed around porphyroblasts, and strain shadow extinction was obliterated. Microcline growing from pre-schistosity porphyroblasts into the polygonised quartz-ribbons indicates a post- D_2 metasomatism. Field evidence suggests that continuing localised metasomatic events led to the emplacement of pegmatites before D_2 and also during D_3 .

The most common metasediments in the Chibambila Group are quartz-rich; quartzitic and semi-pelitic lithologies predominate. The inference is these lithological types were resistant to the metasomatism which led to K-feldspar growth and the relative lack of pelitic assemblages

suggests they were more susceptible to metasomatism while the schlieric types represent partially transformed metasediments.

On Figure 2 it can be seen that the aplitic and pegmatitic gneiss dykes associated with the Milolo Supergroup follow the regional east-northeast trend. It has been suggested by Tuominen (1961) that potash-aluminosilicate migrates to areas of low pressure during deformation and it may be that the dykes in the Milolo Supergroup represent zones of reduced pressure in fold hinges which occurred during deformation.

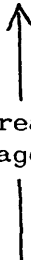
4. PETROGENETIC SYNTHESIS FOR THE GRANITIC GNEISS GROUPS

The purpose of this section is to produce a petrogenetic model for the genesis of the Chisomo granitic gneisses which is consistent with the petrogenesis of the individual types outlined above. The field relationships and textural development are first reviewed in order to establish the sequence of gneiss group formation.

4.1 Field Relationships

From field relationships it is possible to establish the relative ages of the four gneiss groups. The intrusive relationships of the Mwila Gneiss Group and the Migmatite Gneiss Group into the Nkondo Group suggest that this group is the oldest of the four. The relationship between the Mwila Gneiss Group and the Migmatitic Gneiss Group is not so clear cut. In the field there is a gradual transition from migmatitic gneisses through a homogeneous phase into typical Mwila Gneiss Group suggesting a very close genetic relationship. However, the presence of aplitic veins intruding the migmatites pre-D₂ suggests that the migmatites are older than the Mwila Gneiss Group. There is strong petrographic evidence to show that the Chibambila Group is composed of feldspathised metasediments and intruded by non-dilational metasomatic pegmatite dykes. The close association of this group with the Mwila Gneiss Group indicates that the Chibambila Group is a metasomatically derived group peripheral to the Mwila Gneisses and a close genetic link is indicated.

The sequence of gneiss formation may be summarised as:

- | | | |
|----|--|--|
| 4. | Nkondo Group | 
increasing
age |
| 3. | Diaterites of the Migmatite Gneiss Group | |
| 2. | Mwila Gneiss Group Formation | |
| 1. | Chibambila Group | |

4.2 TEXTURAL DEVELOPMENT

It has been shown that the quartz-ribbon texture may be used as a datum in establishing the sequence of textural development. On this basis it is clear that, except for the Mwila Gneiss Group, all the gneiss groups show the same textural development. The stages recognised are as follows:

- | | | |
|----|--|-----------------|
| 1) | Plagioclase blastesis. | M_1 D_1 |
| 2) | Sericitisation and saussuritisation
of plagioclase. | |
| 3) | (a) Microcline growth replacing
plagioclase. | |
| | (b) Development of clear rims
to plagioclase insets. | |
| 4) | Myrmekite formation. | |
| 5) | Formation of secondary crystallo-
graphically oriented muscovite. | |
| 6) | Formation of quartz-ribbons and
microcline augen and plagioclase
porphyroblasts. | D_2 (Tumbide) |

- 7) . Partial polygonisation of the quartz M_2
mosaic and ribbons.
- 8) Replacement of quartz-ribbons by
microcline.

Alteration of microcline to muscovite and carbonate is probably coeval with stage 5).

The recognition of the foregoing stages which led to the development of the gneiss textures and their recognition in associated metasediments of the Nkonsolo Group and metasedimentary enclaves is of petrogenetic significance. The development of the gneisses can be thought of as taking place in a metasedimentary pile, their relative positions of formation in the pile being governed by conditions of temperature and pressure in the simplest case. In terms of metamorphic grade the Migmatite Gneiss Group shows a higher grade assemblage in the associated calc-silicate bands than do the calc-silicates of the Mwila Gneiss Group (Section 2.3). This represents a prograde sequence towards the Migmatite Gneiss Group. The second consideration is that the Nkondo Group shows a broad transition from metasediments through plagioclase blastite of the Nkonsolo Group into the Nkondo Group. An increase in the intensity of plagioclase blastesis is noted in this direction.

The intrusive nature of the Mwila Gneiss Group into the Nkondo Group has been demonstrated indicating, from the simple model proposed, that it formed at a lower crustal level. It is therefore possible to propose that the gneiss groups, in the following order, Nkondo

Group, Mwila Gneiss Group, Migmatite Gneiss Group, represent a prograde sequence of formation.

4.3 PETROGENESIS

Granitic rocks are widely exposed in the Baltic Shield and it was Eskola (1932) who formulated the tectonic classification of granites which was later elaborated by Marmo (1955). Table 6 shows the features which according to Marmo are useful in the recognition of syn- and late-kinematic granites.

A general comparison of features listed with those already described for the Nkondo Group and the Mwila Gneiss Group shows striking similarities. All the syn-kinematic features are developed in the Nkondo Group and the late-kinematic features are present in the Mwila Gneiss Group. Table 6/(1) however indicates that late-kinematic granites are normally massive, whereas the Mwila Gneiss Group is gneissose and the foliation of the late-kinematic granite is post intrusion as intrusive contacts are foliated. The foliation is due to D_2 -tectonism. With reference to point (6), Table 6, the syn-kinematic rocks were said generally to be granodiorites, although the Nkondo Group is potash-rich compared with granodiorite. Late-microcline has been shown to be present and so these rocks are in fact granitised granodiorites.

Figure 10 shows the differentiation index, defined by Thornton and Tuttle (1960), plotted against various oxide percentages for the Nkondo Group and the Mwila Gneiss Group and indicates a continuous series from 75 to 94. Marmo (1973, p 82) points out that there

TABLE 6

FEATURES OF SYN- AND LATE-KINEMATIC GRANITES

Syn-kinematic features	Late-kinematic features
(1) They are predominantly gneissose and concordant with the enclosed schists.	Predominantly massive and usually cutting other rocks discordantly including syn-kinematic gneisses.
(2) Contacts are usually gradational and the appearance of these granites as metatects of migmatites is unusual.	Contacts usually sharp and the granites frequently form migmatites with older rocks.
(3) Basic inclusions are frequent and are typical of syn-kinematic rocks as are lenses and strips of all kinds of basic rocks. They are concordant to the gneissosity of the "granite".	Basic inclusions are infrequent and usually lacking, but skialithic, ghost-like remnants of strongly assimilated older rocks may be preserved.
(4) They are usually comparatively coarse-grained, often closely related to the veined and augen varieties, containing large quartz and feldspar porphyroblasts.	They are usually fine-grained, often pinkish and tend to be aplitic, porphyritic varieties are uncommon.
(5) Most of the field evidence suggests that they were formed by the granitisation of older rocks.	The field evidence predominantly supports the view that their origin was due to intrusion.
(6) In their composition the syn-kinematic granites tend to be granodiorites and even quartz diorites.	The late-kinematic granites are chemically true microcline granites.

After Marino (1955)

is usually a marked break between syn- and late-kinematic granites in variation diagrams with intermediate members lacking, thus demonstrating that they do not represent a consanguineous magma series. This break is not apparent in Figure 10 and the intermediate members must therefore have been formed metasomatically in view of the field and petrographic evidence already put forward. A similar interpretation for the absence of the break in differentiation diagrams was proposed by Simonen (1960), who pointed out that granitisation always trends towards rocks of microcline-granite composition. This transformation is illustrated also by the schlieric, feldspathised nature of the Nkondo Group enclaves in the Mwila Gneiss Group.

With reference to point (5) Marmo states that syn-kinematic rocks were formed by granitisation of older rocks. In the preceding discussion on the Nkondo Group, examples to support this were noted. Particularly informative is the recognition of a continuous series of plagioclase blastesis from Biotite Schist → Nkonsolo Group → Nkondo Group, a process of granodioritisation (Marmo 1973). The granitisation was a later event. The preservation of lenses of Nkonsolo Group, plagioclase blastite in the Nkondo Group points to its blastic origin. The alkali diagram (Figure 7) shows no major variation in soda content between metasediments and the Nkondo Group and soda metasomatism may therefore be disregarded as a major mechanism in their genesis. The absence of plagioclase blastic textures in the Mwila Gneiss Group is rather negative evidence against derivation from metasediments by blastesis and the recognition of early aplitic-like patches in the groundmass would support a magmatic origin.

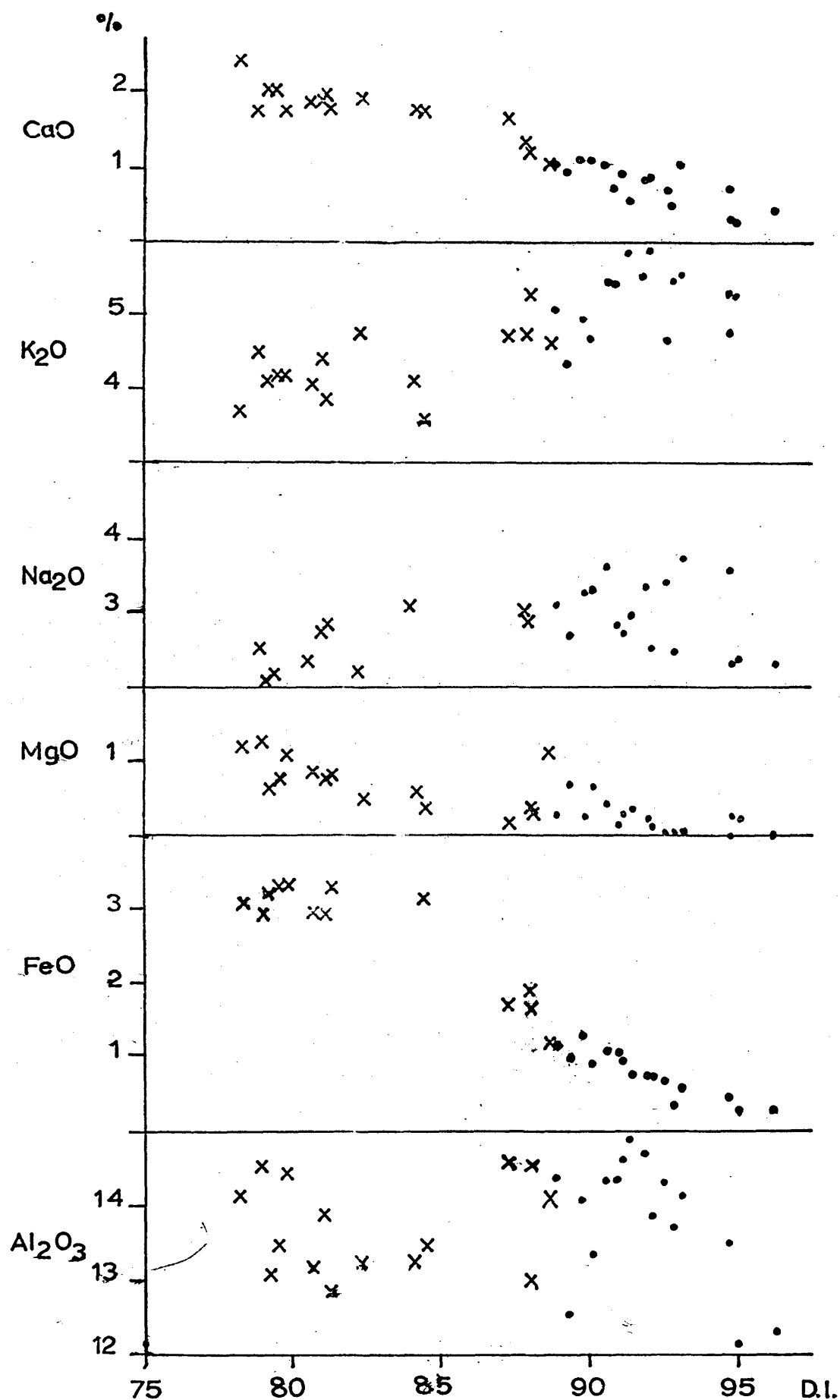


Fig10 Oxide percentage plotted against differentiation index for the Nkondo Group,(crosses),and the Mwila Gneiss Group,(dots).

Basic inclusions are very commonly preserved in the Nkondo Group and, more rarely, in the Mwila Gneiss Group. They were deformed by D_1 and are therefore pre- D_1 and represent relicts of amphibolites intruding an original metasedimentary pile. Quartzite enclaves have been noted within the amphibolites. A striking example of concordance between the Nkondo Group and the metasediments shows conclusively that the former initially developed by mineral blastesis from an original metasediment. North of the Mililo Stream (at TV 600905) a thin continuous band of brown, fine-grained, feldspathic quartzite is enclosed by biotite schist. This band has a marked air-photo expression appearing as a continuous line with a dark tone; it is intermittently exposed along strike and has been traced for a distance of 10 km. To the east the quartzite band is intercalated with biotite pelites and psammities of the Biotite Schist Group. When traced westwards the biotite pelites pass into typical Nkondo Group rocks, but the quartzite band continues into the gneiss and is concordant with the foliation. The evidence favours autochthonous derivation of this group. In the central outcrop of the Mwila Gneiss Group enclaves are exceptionally rare and not even ghost-like remnants are preserved, but they become progressively more abundant through the transitional zone into the Chibambila Group. The Chibambila Group may be a pegmatitic, late-kinematic granite. Such rocks have been described by Harme (1960), as quoted by Marmo (1973, p 88), from the granites of southern Finland where abundant skialithic remnants are present. This correlation is supported by the similar textural development of the two groups. Both paligenetic and metasomatic origins have been proposed for late-kinematic granites. Ramberg (1952, p 239) suggested that the large-scale architecture of the late-kinematic rocks, eg, preservation of registers, argues in

favour of formation by metasomatism. He suggested that the presence of isolated marble bands in granitic gneisses occupying areas of thousands of square miles could only be interpreted in terms of a metasomatic origin of the granitic gneisses. Similar reasoning may be used in the Chisomo Area to account for the extension of the main calc-silicate band and the Lubo Quartzite into the Mwila Gneiss Group. Petrographic studies of contact rocks confirm that metasomatism operated. The presence of intrusive contacts and the recognition of early formed aplitic textures argues in favour of a paligenetic origin as does the close correspondence of the potash-rich composition and the experimental minimum melting composition. Figure 6 showed that the Mwila Gneiss Group is potash-rich relative to a minimum melt in the system Q-Ab-OR, explicable as a metasomatically transformed granite which formed at an isobaric minima. Petrographic evidence that an original aplitic texture has been feldspathised supports this. It is therefore concluded that a late-kinematic minimum-melting granite intruded the Nkondo Group locally and that subsequent metasomatism transformed the surrounding rocks and the early Mwila Gneiss Group to the rocks of microcline granite composition now seen. This metasomatism would account for the presence of the Chibambila Group, and the feldspathisation of the Lubo Quartzite and the main calc-silicate horizon. The Mwila Gneiss Group is therefore both para-autochthonous and intrusive.

The late pre-D₂ aplitic and pegmatitic veins, which have previously been shown to be non-dilational and therefore metasomatic in origin, probably formed during this phase. Simonen (1960) explained the microcline granites of the Finnish Svecofennides in the same way to reconcile conflicting metasomatic and intrusive features.

The genesis of the palingenetic Mwila Gneiss Group has already been discussed in relation to the work of Cann (1970) and Harris et al (1970); and it was assumed to have derived as a wet melt from the metasedimentary pile. The transition zone already mentioned in connection with the Migmatitic Gneiss Group is significant as it is believed to be the source of the palingenetic melt. The broad transitional contact between the two groups and the presence of late-aplitic veins in the diatexites are arguments in favour of derivation of the Mwila Gneiss Group from the Migmatitic Gneiss Group. Chemically the two groups are distinct, the Migmatites contain less potash and calcium than the Mwila Gneiss Group (Figure 5), but on the differentiation diagram (Figure 11) they show a continuous series overlapping with the Mwila Gneiss Group. Within the Migmatitic Gneiss Group, homogenisation took place with the development of a palingenetic melt, the Mwila Gneiss Group, which intruded the overlying pile as a late-kinematic granite. A characteristic of many of the Older Granites of Scotland is extensive peripheral development of regional migmatite some 20 to 40 km in width. One such is the Loch Coire Complex investigated by Brown (1967, 1971) who showed that metasomatism outside the confines of the complex was an important event and that the rocks so formed do not have compositions related to granite minima. He was also able to demonstrate a mobility of elements, indicating that K_2O , the most mobile, occurs at the outer limits of the complex.

Experimental evidence from Tuttle and Bowen (1958) and Orville (1962) indicates that during heating experiments there is a migration of potassium, as potassium aluminosilicate, along thermal gradients to lower temperature zones and Orville (1962) concluded that this effect would account for the widespread metasomatism observed associated with partially

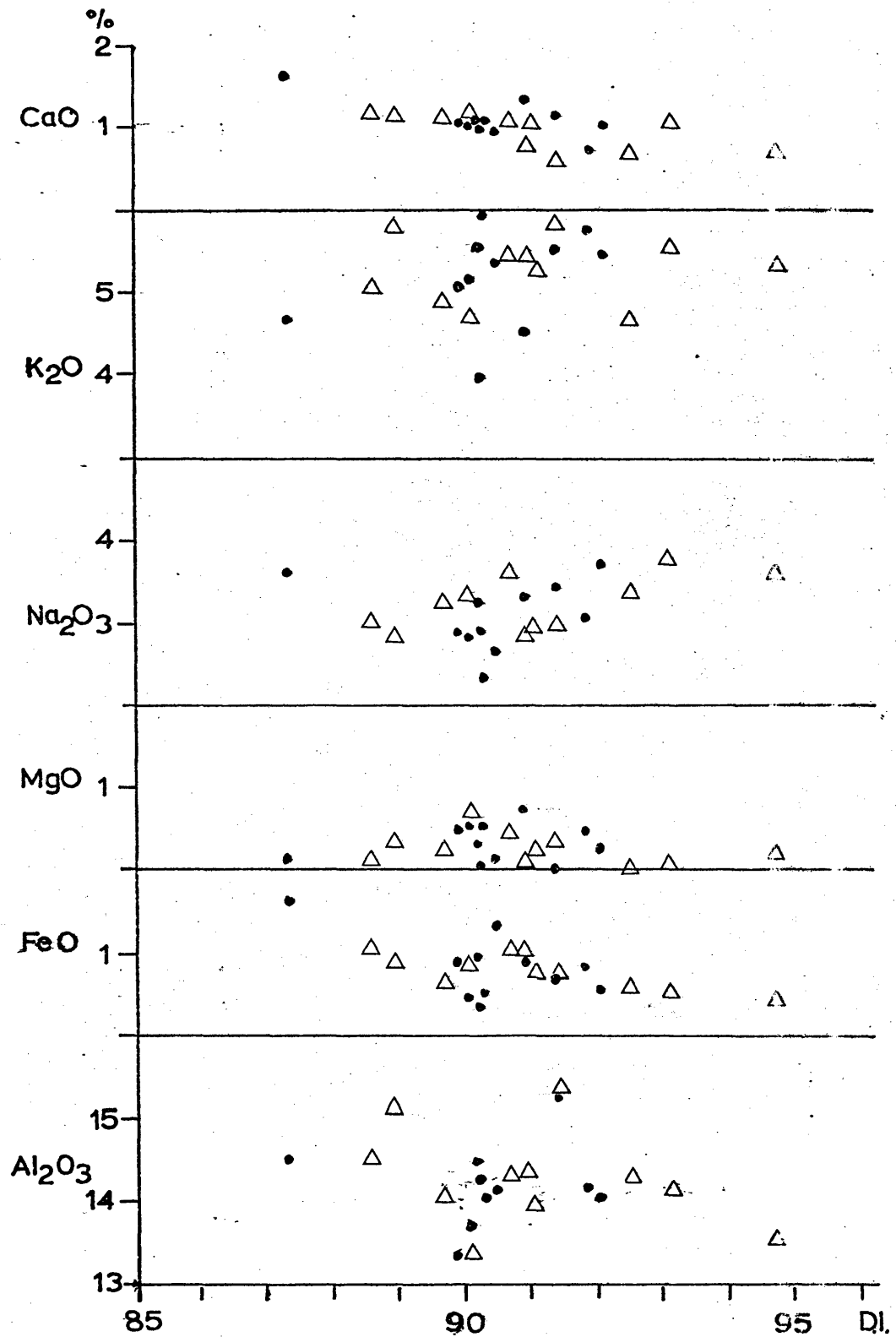
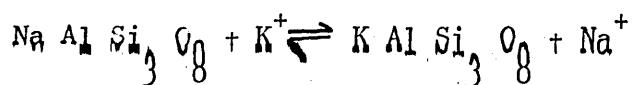


Fig11 Oxide percentage plotted against differentiation index for the Mwila Gneiss Gp., Δ , and the Migmatitic Gneiss Gp., $\bullet$.

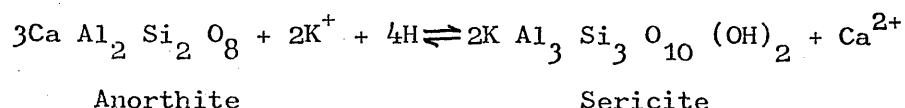
melted rocks. In the Chisomo Area the late-microcline appears to postdate the intrusion of the Mwila Gneiss Group since both the aplitic mosaic of the groundmass is feldspathised and K-feldspar porphyroblasts are developed in the intruded Nkondo Group. X-ray determinations of triclinicity of microcline porphyroblasts, hand-picked from the two groups, give identical values of Δ . The method of determination used was that of Goldsmith and Laves (1954). The fact that the microclines show identical structural states strongly suggests that they were formed at the same time under similar physical conditions. This would argue against migration of K-aluminosilicate followed by intrusion of the Mwila Gneiss Group and the model proposed by Marmo (1973, p 184) based on Orville's work seems to be more acceptable. In this model there is an initial migration of K-aluminosilicate to zones of lower temperature, contemporary with the formation of the syn-kinematic gneisses. It is assumed that the K-rich fluids concentrate in a higher zone and are in equilibrium with the rock host. Subsequent uplift of the syn-kinematic gneisses, possibly due to the rise of the late-kinematic granites, causes these rocks to enter the zone of K enrichment. The gneisses would become granitised and the late-kinematic, minimum melting granite would become potash-rich relative to the minimum melting composition.

The mechanism of the granitisation process indicated by the petrography of these rocks is essentially the replacement of plagioclase by microcline and is accounted for by the experimental work of Orville (1963). He found that with a falling temperature potash feldspar replaces sodium feldspar and showed that the vapour phase in equilibrium with

two alkali feldspars becomes progressively poorer in K as the temperature decreases. The temperature dependence of the K/Na ratio in the fluid phase provides a potential for alkali metasomatism. Alkali-bearing fluid in equilibrium with two alkali feldspars at a high temperature will, upon cooling or entering a lower temperature zone, be capable of replacing Na-rich feldspar according to the following reaction:



The lowering of the K/Na ratio to maintain equilibrium can also be achieved by the reaction:

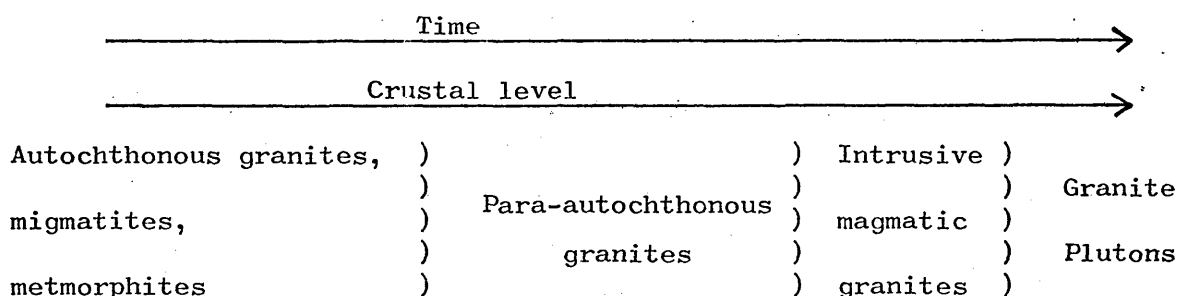


This reaction has already been invoked to account for the sericitisation of plagioclase and may also account for the presence of epidote.

In this model the zone of concentration of potassium would be the Chibambila Group. In a model proposed by Fyfe (1970) the rise of a granite essentially follows Stoke's Law. A melting zone is envisaged with a collection zone above of the lighter granitic melt fractions. - this would be the diffuse contact between the Mwila Gneiss Group and the Migmatitic Granite Gneisses. A large bulge would form at the collection zone until a drop can move off due to viscosity differences. According to Ramberg (1970), the viscosity contrast between the collection zone and the surrounding rock would cause a mechanical instability or inverted density stratification and favour the development of a bulge.

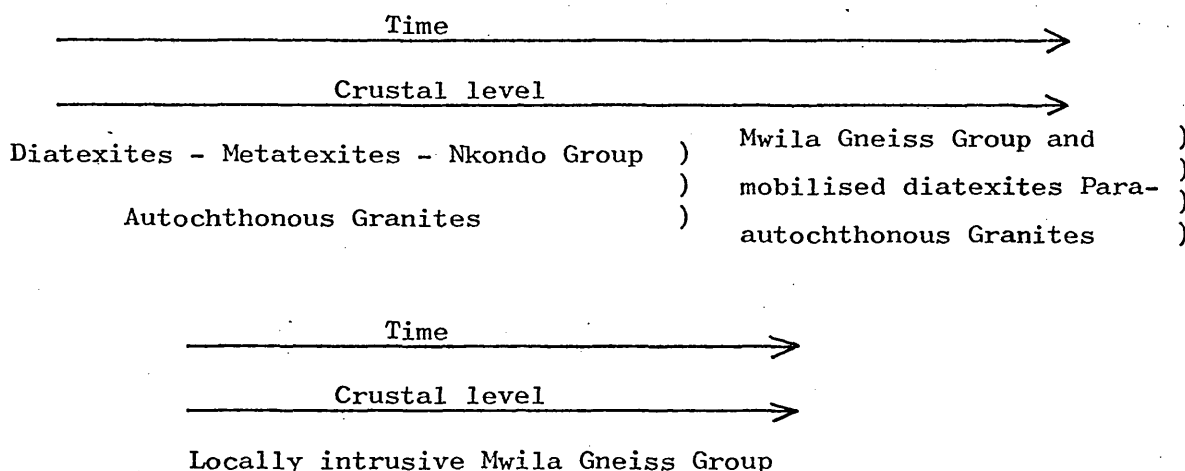
The model outlined above to account for the spatial distribution of the individual gneiss groups corresponds to Read's (1955) granite series. Read stated (Read 1957, p 374) 'It is becoming clear that the composition, setting and form of an igneous rock are all specific and related qualities expressing the relevant magmatic and crustal history.....there are granites of various kinds, and they are related to various settings and events.

The granites of various kinds make up the Granite Series.....which
can be presented thus: '



Read (1955, 1957, p 395) also pointed out that there is also a 'general tendency for the late-granites to be more potassic than the earlier terms'. This feature is readily recognisable in the differentiation diagrams already presented; the Mwila Gneiss Group is relatively richer in potassium.

Adapting the above scheme to the present area, the Chisomo rocks occupy the following positions in the Series:



The time interval required for the development of the series has been shown to have ranged from during D_1 to late- D_1 and before D_2 . Metasomatic textural modifications occurred before D_2 and after D_2 . The absolute time interval cannot be stated as age determinations are not available for D_1 . The absence of true granite plutons is probably due to the level of exposure and in this respect the series is incomplete in the area of study.

4.4 Conclusions

A group of autochthonous, syn-kinematic, granitic gneisses, the Nkondo Group, was derived from a metasedimentary sequence of quartzites and biotite schists by processes of mineral blastesis initiated during D_1 . Concomitant with the formation of the Nkondo Group there was migration of potassium to higher levels in the metasedimentary pile and to regions of lower temperature. Palingenesis in the higher grade zones of the sequence led to the formation of the Mwila Gneiss Group, a late kinematic granite, which locally intruded and domed the overlying Nkondo Group into the zone of K concentration where the whole sequence was feldspathised. The Mwila Gneiss Group represents the para-autochthonous equivalent of the Migmatite Gneiss Group, a group of autochthonous granitic rocks formed under conditions of the highest grade metamorphism.

in this area.

4.4.1 Regional Significance of the Chisomo Petrogenesis:

A comparison with the Mkushi Gneiss Group

The field characteristics of the Mkushi Gneiss Group have already been compared to the Nkondo and Mwila Gneiss Groups of the Chisomo Area. Published textural information is rather incomplete. In a description of the biotite, porphyroblastic gneisses Stillman (1965) recognised that Tumbide (D_2) shearing led to the development of augen and lens textures in these gneisses, an observation in direct agreement with the Chisomo Area. He failed however to note that they are syn-kinematic gneisses and must have formed during an earlier pre-Tumbide phase. Texturally the microcline porphyroblasts show similar development to those in the Chisomo Area and pools of quartz and biotite inclusions are present. The feldspathisation was thought to have developed from the associated fine grained, banded gneisses at the same time as Tumbide metasediments were granitised. During the Irumide phase intense shearing obliterated much of the Tumbide texture and feldspar porphyroblasts are cracked and granulated.

In the Chisomo Area, the D_3 -Irumide phase did not have such a texturally destructive effect and porphyroblasts were gently crenulated along with D_2 -ribbon texture (see Plate 88). This fact accounts for the relative ease in deciphering pre-Tumbide textural developments in the Chisomo Area.

Kerr (1973) proposed that the Kalonga Series and the Musofu Formation

of Stillman are equivalent. The Irumi Formation is considered by the present writer to represent relics of the granitised basal part of the Musofu Formation. Stillman seems to have made the original subdivision merely on the presence of intraformational conglomerates and opaque ore banding in the Musofu Formation and not on the presence of a well defined unconformity or structural break. Stillman (1965, p 22) wrote that both formations show evidence of the Tumbide phase.

The scheme of textural development proposed for the Chisomo Area leads to the conclusion that the Mkushi Gneiss Group represents part of a transformed metasedimentary sequence corresponding to the Irumi and Musofu Formations and Kalonga Series, which has subsequently been intruded by late-kinematic, pre-Tumbide, aplitic granites and that the Mkushi Gneiss Group represents an autochthonous and para-autochthonous sequence of granitic rocks derived from rocks of Musofu Formation and Kalonga Series age. The Irumi Formation then represents relics of these formations within the Mkushi Gneiss Group.

With reference to Table 1, the above implies that the sequence recognised by Stillman and later workers in the Irumide Fold Belt is stratigraphically incorrect. Previous workers' sequences are inverted relative to the Chisomo Area.

Furthermore, if the correlation of the Musofu Formation and Kalonga Series with the Muva is upheld, the Mkushi Gneiss Group is a post-Muva, autochthonous and para-autochthonous granitoid complex.

Plate 1. Microcline (Mic) replacing
amphibole (Amph) in a calc-silicate.

9FD 658

Crossed nicols

(x 256)

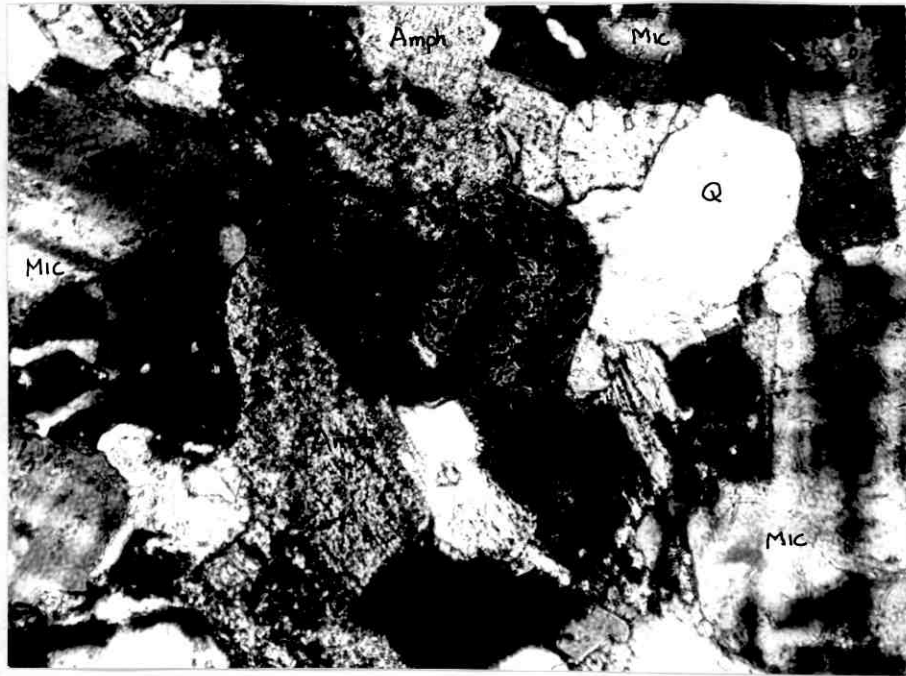


Plate 2. Banded plagioclase blastite. A more psammitic band, B, occurs in pelitic plagioclase gneiss, A, showing development of segregation leucosome, C, coplanar with banding and schistosity. It is possible that the banding of the leucositic layers is tectonic and represents drawn out F_2 folds.

Plate 3. Plagioclase porphyroblast which shows idioblastic, equant habit. The foliation defined by polygonised quartz-ribbons deforms around the blast. The plagioclase also shows strain extinction and sericitisation (ser.) is particularly well advanced along twin planes. The inclusions of quartz and biotite suggest the porphyroblastic growth of the plagioclase into the groundmass.

9FD 563

Crossed nicols

(x 112)

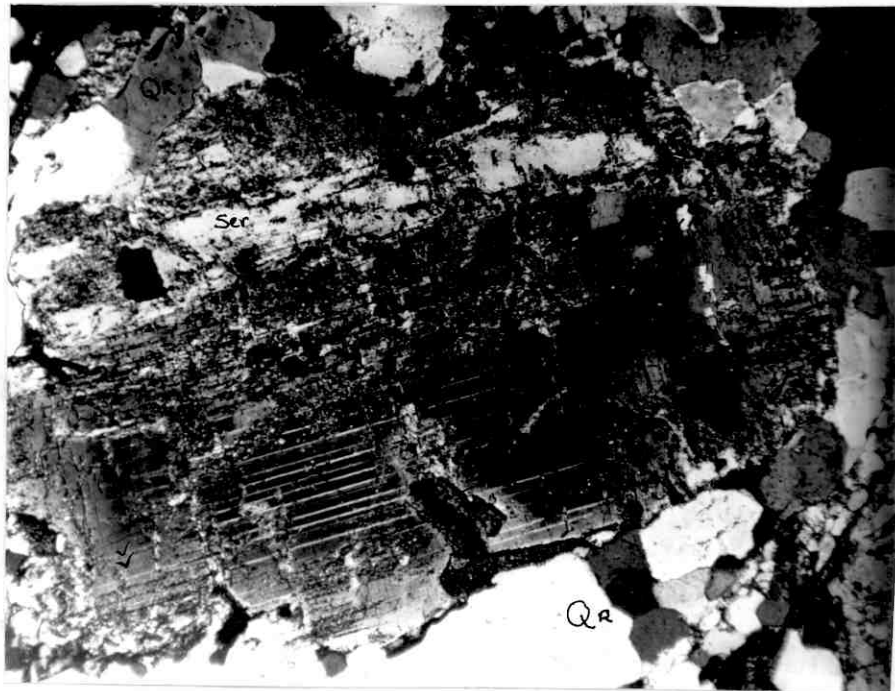
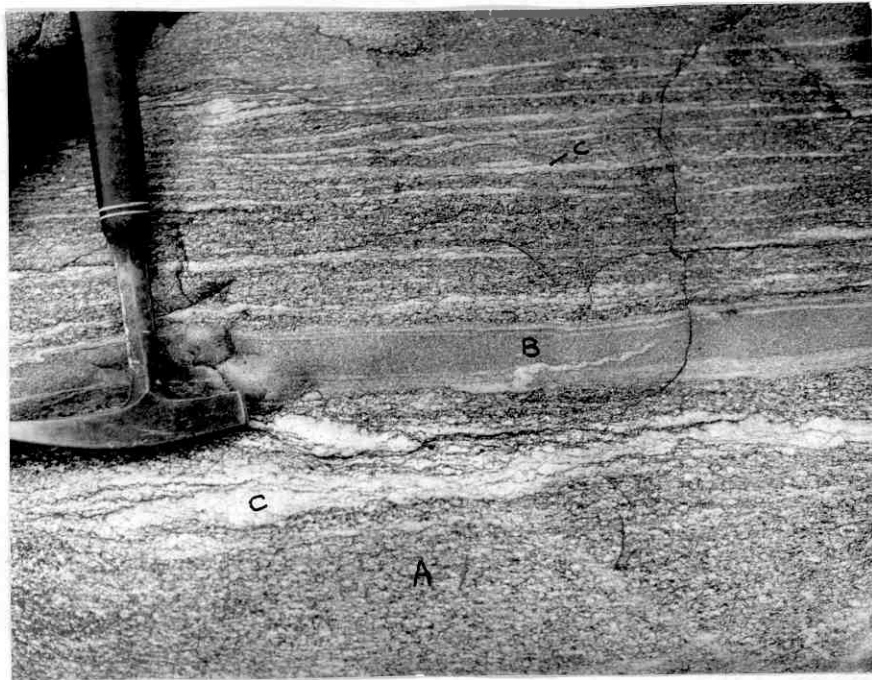


Plate 4. Examples of pre-Schistosity plagioclase
blastesis.

The plagioclase shows textures very similar to the metasomatic textures of microcline. The plagioclase appears to have grown by advance along qtz grain boundaries into the groundmass. Incorporation of the groundmass into the growing plagioclase gives rise to the qtz blebs and mica flakes so commonly seen.

9FD 560 Crossed nicols (x 112)

9FD 559 Crossed nicols (x 112)

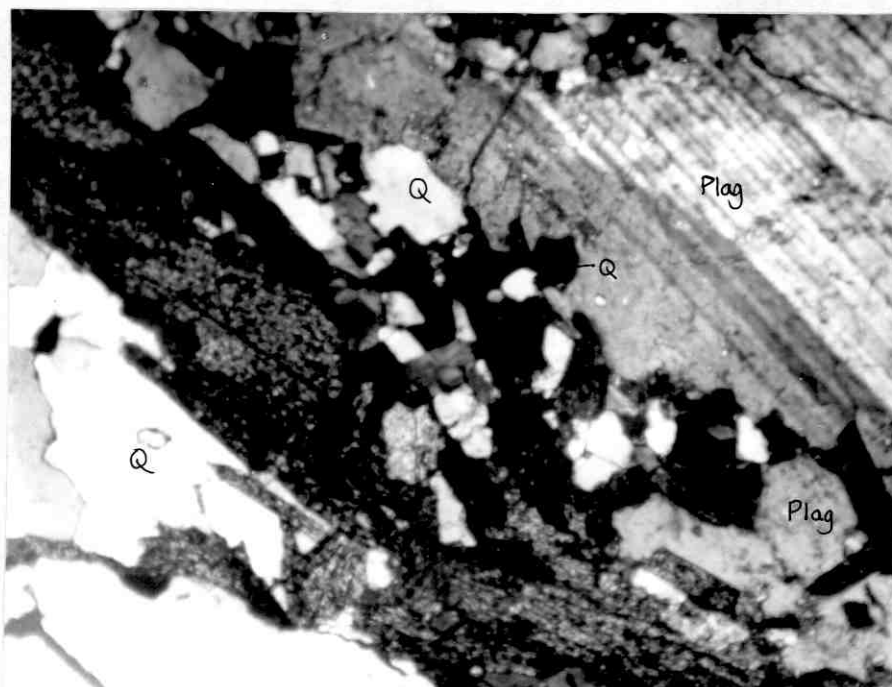
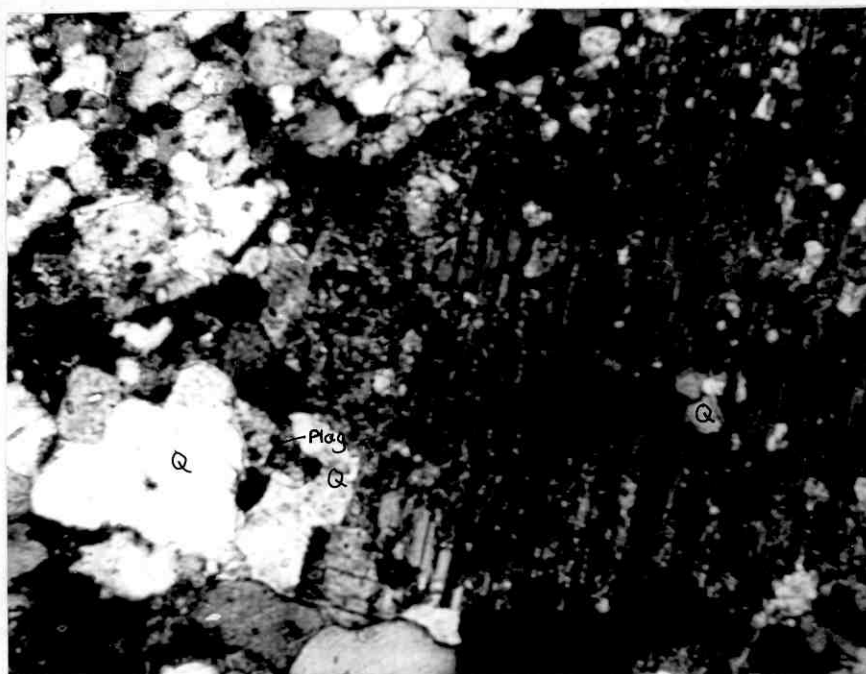


Plate 5. Early plagioclase, plag 1, surrounded by a later generation of plagioclase, plag 2. The blast shows irregular extinction due to its polygranular nature. The blastic process has advanced to such a stage that adjacent plagioclases have merged. The presence of the irregular quartz bleb (Q) and the irregular corroded nature of plag 1 is taken as evidence of blastesis.

9FD 559 Crossed nicols (x 72)

Plate 6. Xenoblastic plagioclase porphyroblast showing later replacement by muscovite (musc.). The irregular replacive contact at the left of the crystal and the presence of partially oriented muscovite flakes along plagioclase twin planes indicate that the sericitization was post-plagioclase blastesis.

9FD 561 Crossed nicols (x 112)

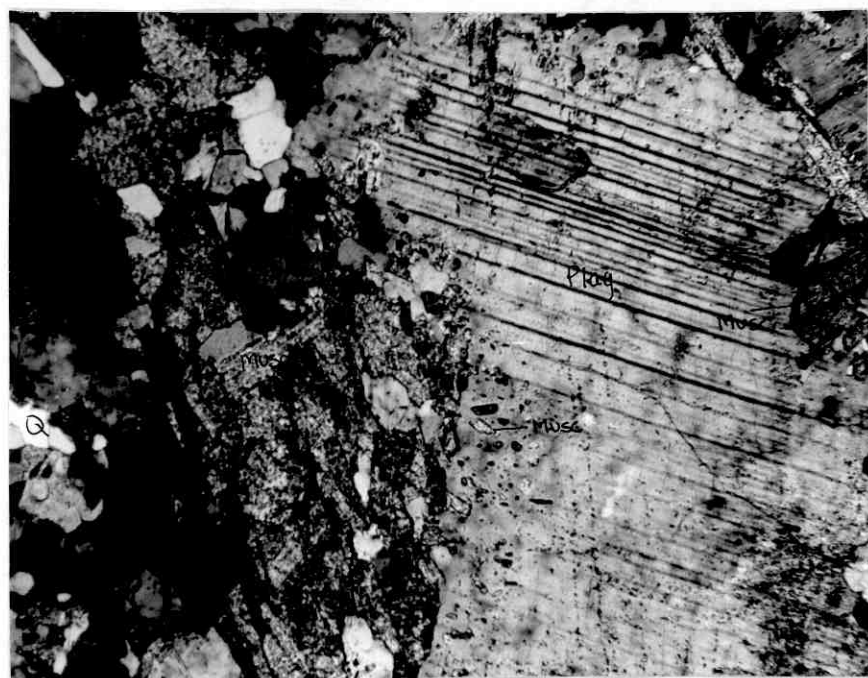


Plate 7. Biotite, K-feldspar porphyroblastic gneiss of the Nkondo Group. The rock has been tectonised during D_2 , the augen of K-feldspar, A, developed during this event.

TV 602887

Plate 8. General appearance of Biotite, K-feldspar porphyroblastic gneiss. Note the subidioblastic nature of the K-feldspar megacrysts (Kf). There is a weak preferred orientation of K-feldspar in the direction of the arrow indicated.

TV 655858

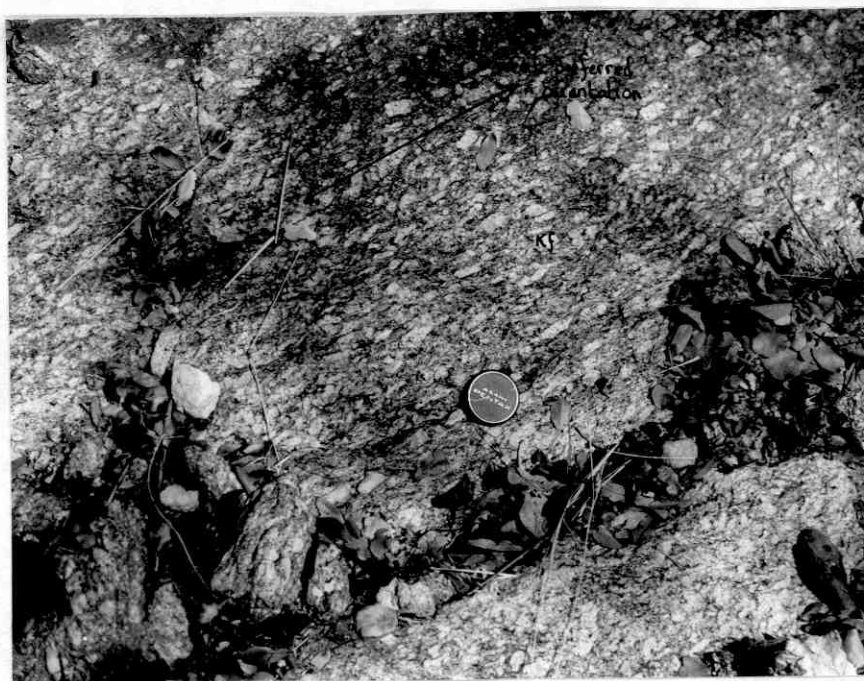
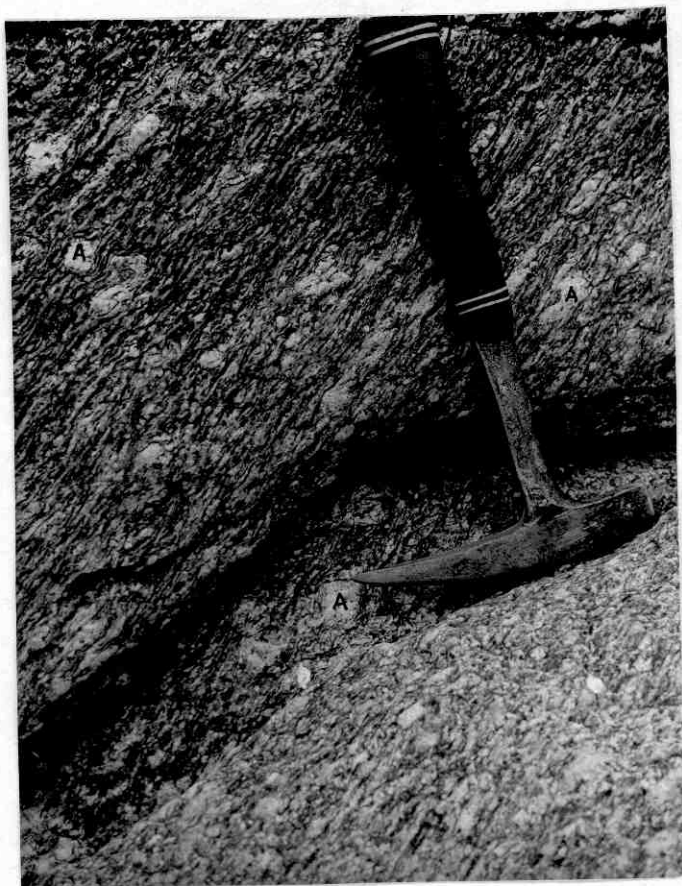


Plate 9. Contact between Nkondo Group (N) and Mwila Gneiss Group (M). Note the increased intensity of augen development near the contact which is probably related to a competency difference between the two groups.

TV 570843

Plate 10. Schlieric lenses of Nkondo Group, porphyroblastic gneiss within Mwila Gneiss near the contact.

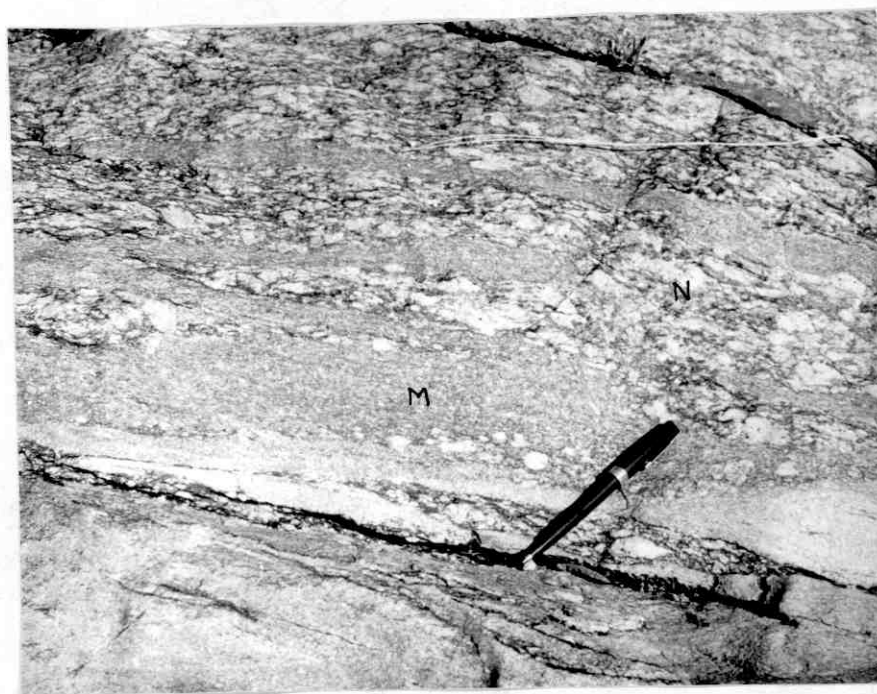
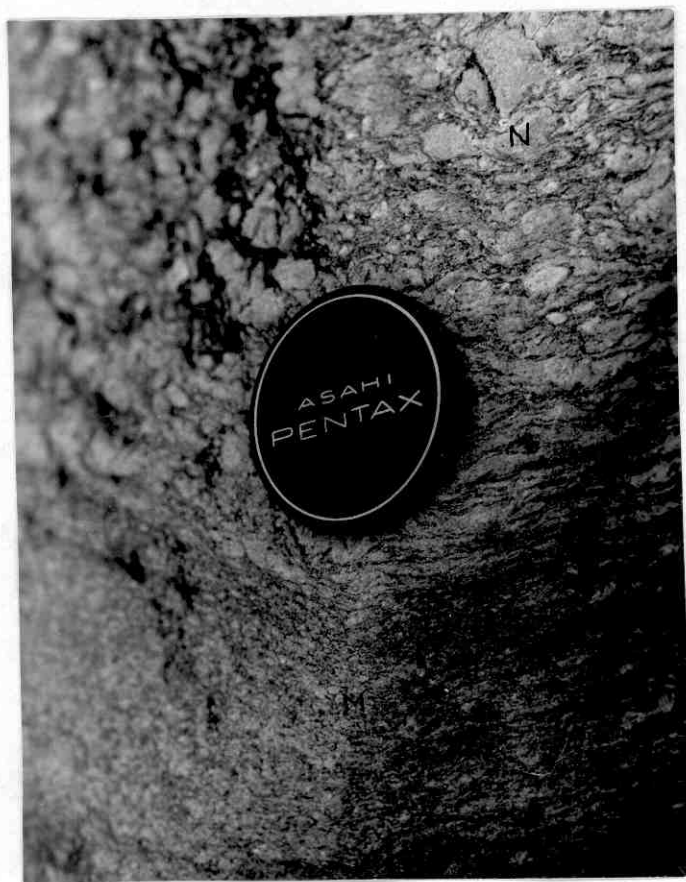


Plate 11. Schlieric enclaves of Nkondo Group porphyroblastic gneiss (N) in Mwila Gneiss Group (M). Indicates the post-Nkondo Group age of the Mwila Gneiss Group.

Plate 12. Dyke of Mwila Gneiss Group granitic gneiss (M) ^m_^ Nkondo Group, porphyroblastic gneiss (N)

TV 655852

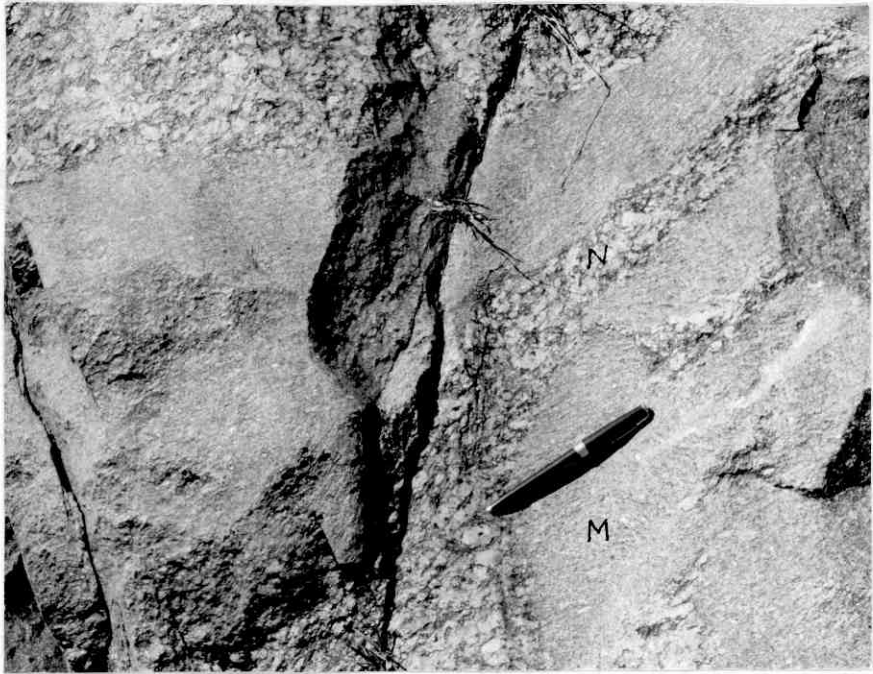


Plate 13. Rounded enclave of Nkondo Group porphyroblastic gneiss (N) in Mwila Gneiss Group (M).

Plate 14. Quartzite enclave (Q) in Nkondo Group porphyroblastic gneiss (N). Note the concordance between the banding in the quartzite (Sb) and the schistosity in the gneiss (Sg) arrowed.

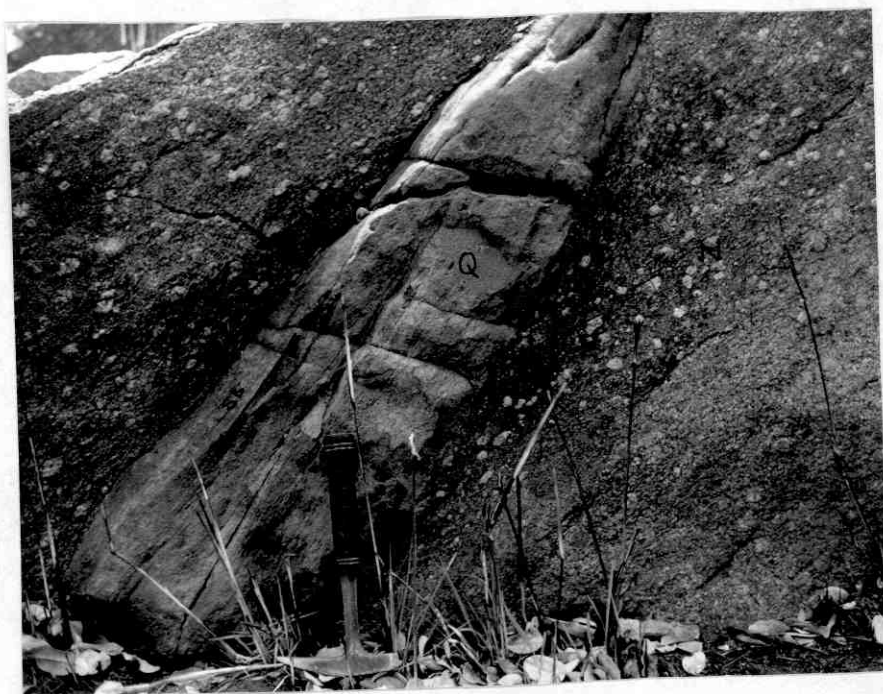


Plate 15. Isometric plagioclase porphyroblast (Plg) showing some sericitisation (Ser) and margin blastesis into the quartz mosaic (Q). The quartz ribbon, QR, deforms around the plagioclase and is polygonised.

9FD 827 Crossed nicols (x 72)

Plate 16. Isometric, rounded plagioclase porphyroblast, pre-kinematic to the polygonised quartz-ribbon. QR. The plagioclase shows blastesis into the groundmass (arrowed) with inclusions of biotite (Bt) and quartz (Q)

9FD 827 Crossed nicols (x 12)

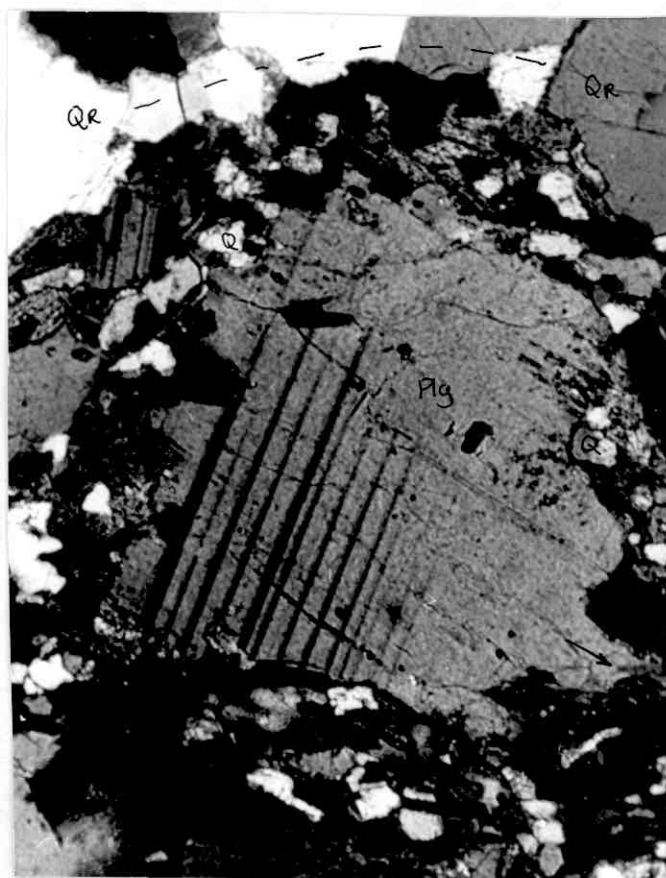
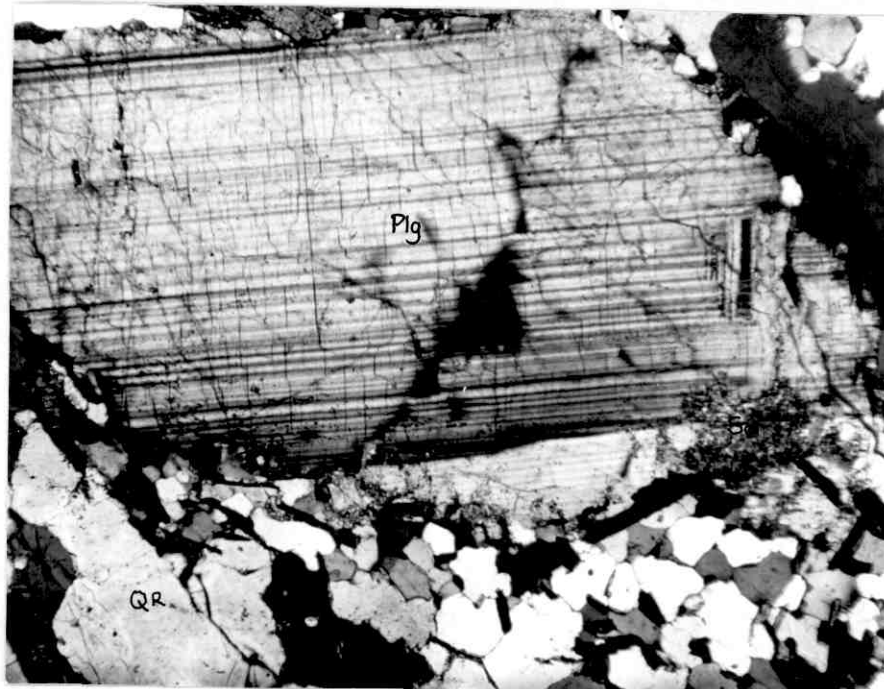


Plate 17. Part of a well twinned plagioclase porphyroblast (Plg 2) showing an earlier included plagioclase (Plg 1). The augen forming event has caused twin plane deformation (arrowed). Marginal blastesis is shown by the partially included quartz (Q) and biotite (Bt). Some twin plane sericitisation is present and sericitisation has also occurred along ill-defined cleavages oblique to the twinning.

9FD 676 Crossed nicols (x 72)

Plate 18. Sericitised (Ser) skeletal looking plagioclase (plg) showing irregular blastesis into the groundmass. The plagioclase is in contact with microcline which contains inclusions of quartz and plagioclase. The plagioclase shows a clear reaction rim against the microcline. Microcline is also replacing the plagioclase top centre of the picture.

9FD 694. Crossed nicols (x 72)

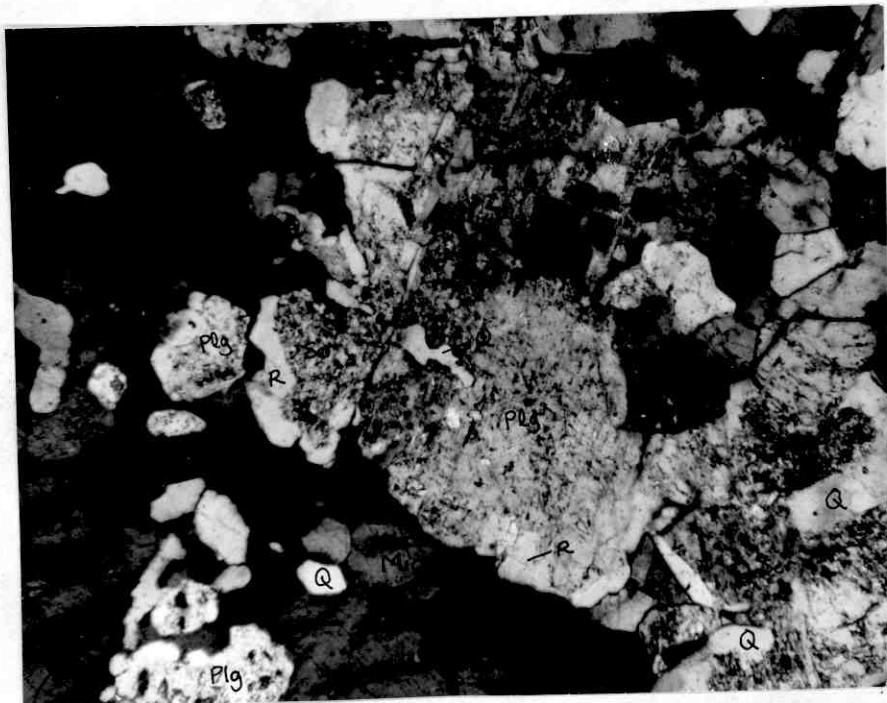
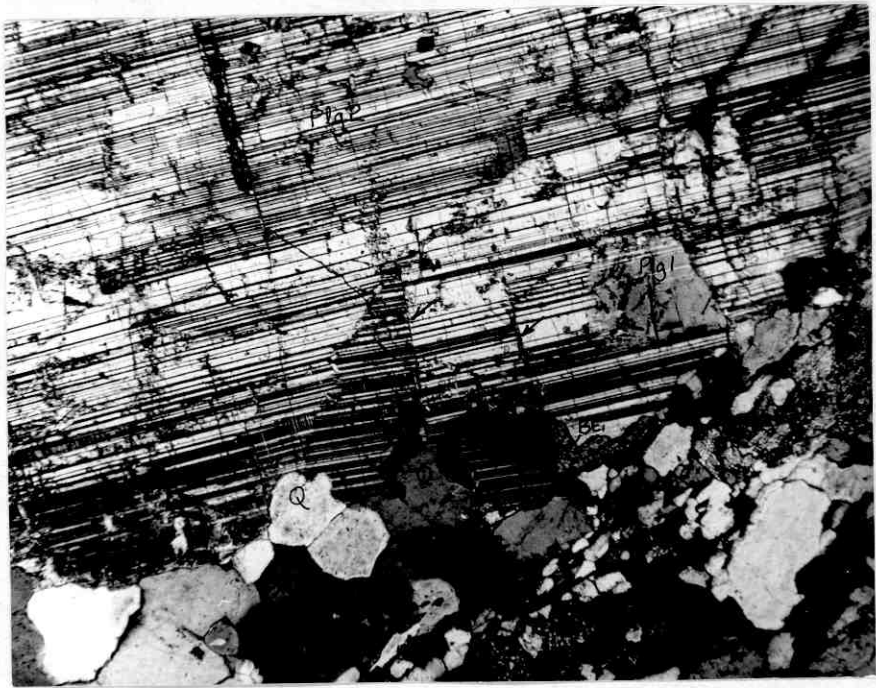


Plate 19. Poikiloblastic plagioclase porphyroblast (Plg) with numerous drop-like quartz inclusions (q) and biotite flake (Bt).

9FD 629 Crossed nicols (x 256)

Plate 20. Plagioclase porphyroblast (Plg) being replaced by muscovite (musc). Marginal blastesis into the groundmass is still evident (arrowed.) Plg B is a good example showing blastesis note the drop-like quartz inclusions (Q) and its polygranular nature by amalgamation with Plg C the contact being defined by a line of quartz blebs. The composite grain Plg C-B occurs in a large embayment of the microcline (Mic) and shows a wide myrmekite marginal zone adjacent to the microcline.

9FD 824 Crossed nicols (x 112)

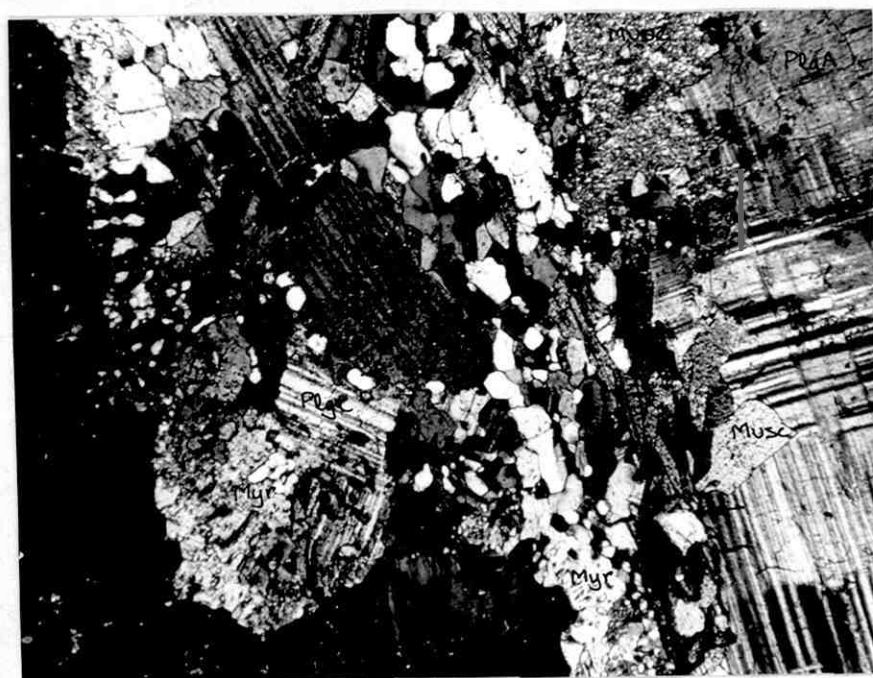


Plate 21. Microcline porphyroblast showing pre-kinematic relationship to the Biotite-quartz-ribbon foliation (Bt - QR). Note the polygonisation of the quartz ribbon and the biotite. Very little strain is now present due to MP₂ annealing. The arrows indicate replacement of the quartz mosaic along grain boundaries.

9FD 568 Crossed nicols (x 72)

Plate 22. Detail of a microcline porphyroblast margin. Note its xenoblastic outline and the numerous quartz inclusions. Plagioclase also occurs. The inclusions originated by growth of microcline into the groundmass and their incomplete replacement.

9FD 629 Crossed nicols (x 112)

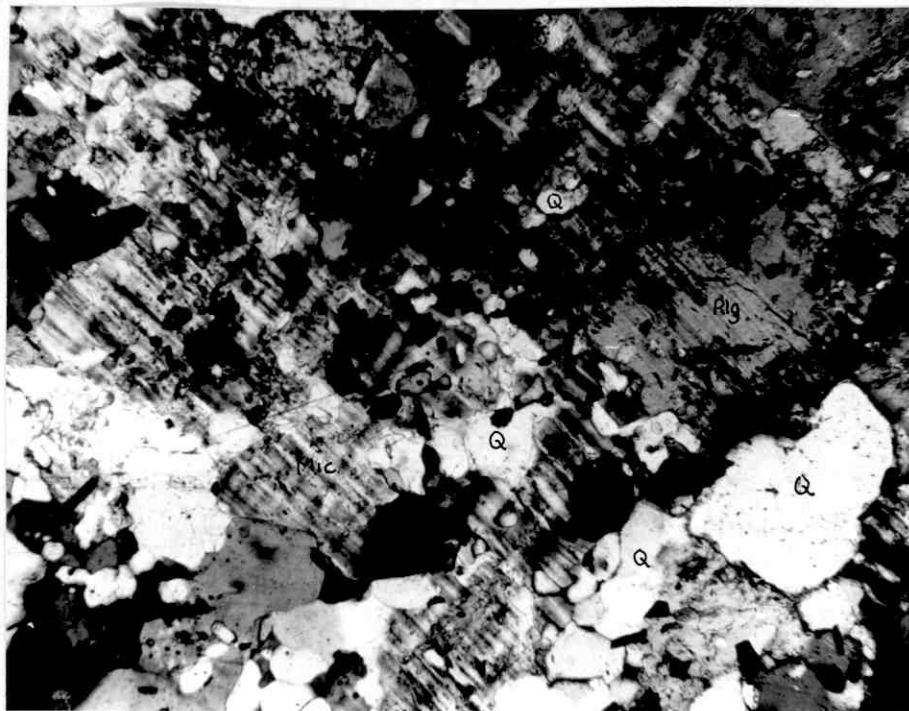
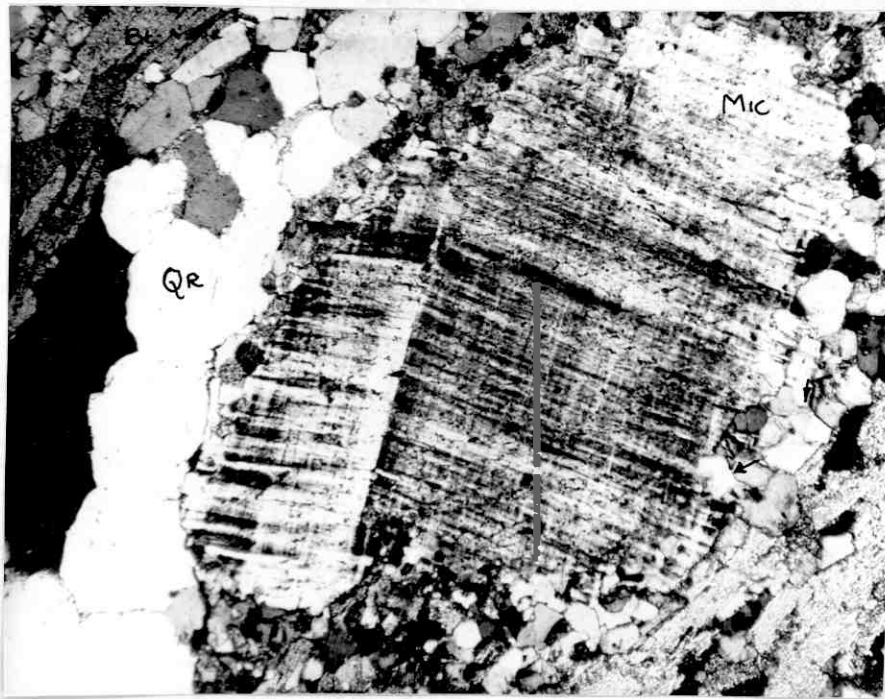


Plate 23. Example of microcline replacing the quartz-ribbon texture (arrowed). A small drop-like quartz inclusion occurs in the prophyroblast.

9FD 667 Crossed nicols (x 112)



Plate 24. Marginal blastesis of microcline into the surrounding quartz mosaic. A grain is being replaced (arrowed) and a small quartz inclusion has resulted in optical continuity with the external grain. A plagioclase inset is also present which shows sericitisation. Smaller xenoblastic remnants occur in the microcline host in optical continuity with the main inset and indicate its extent prior to replacement.

9FD 667 Crossed nicols (x 72)

Place 25. Xenoblastic, skeletal microcline replacing quartz groundmass (arrowed). The embayed irregular margins are characteristic of this texture.

9FD 694 Crossed nicols (x 112)

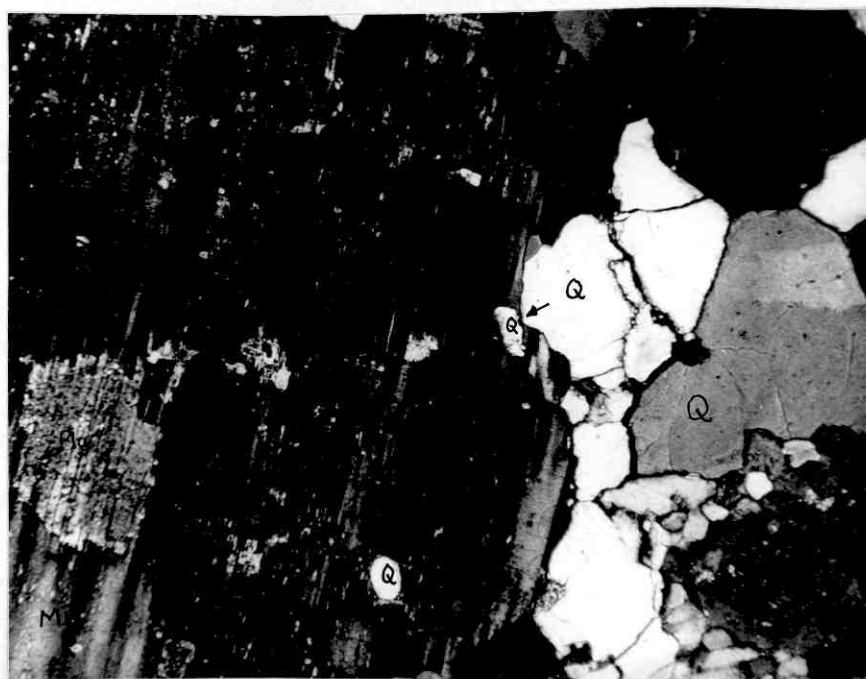


Plate 26. Perthitic orthoclase prophyroblast containing
a groundmass septa.

9FD 694 Crossed nicols (x 112)

Plate 27. Alternation of microcline. The microcline
shows a reticulate network of carbonate veins (Cc) and
muscovite (Musc). A lenticular quartz inclusion is
present.

9FD 565 Crossed nicols (x 256)

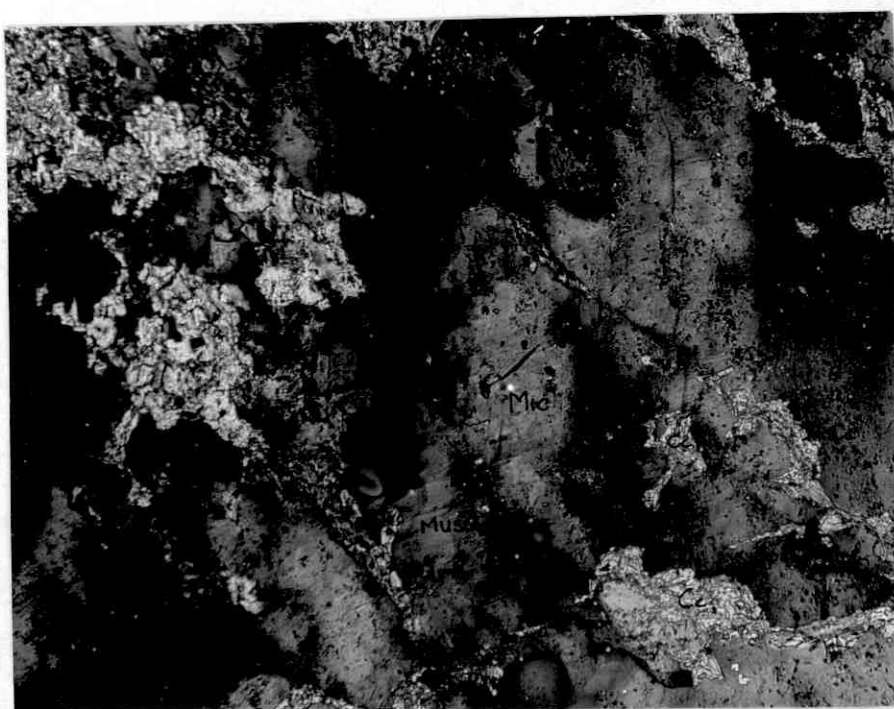
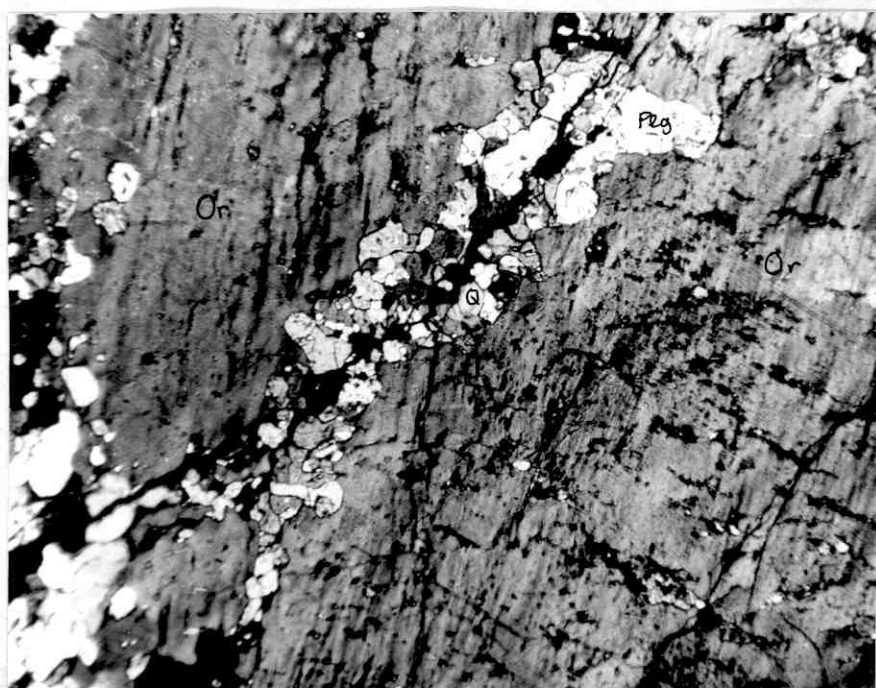


Plate 28. Corroded, sericitised plagioclase inset (Plg)
showing a quartz inclusion (Q) in microcline microperthite.
The margins of the microcline are embayed by myrmekite.

9FD 827 Crossed nicols (x 112)

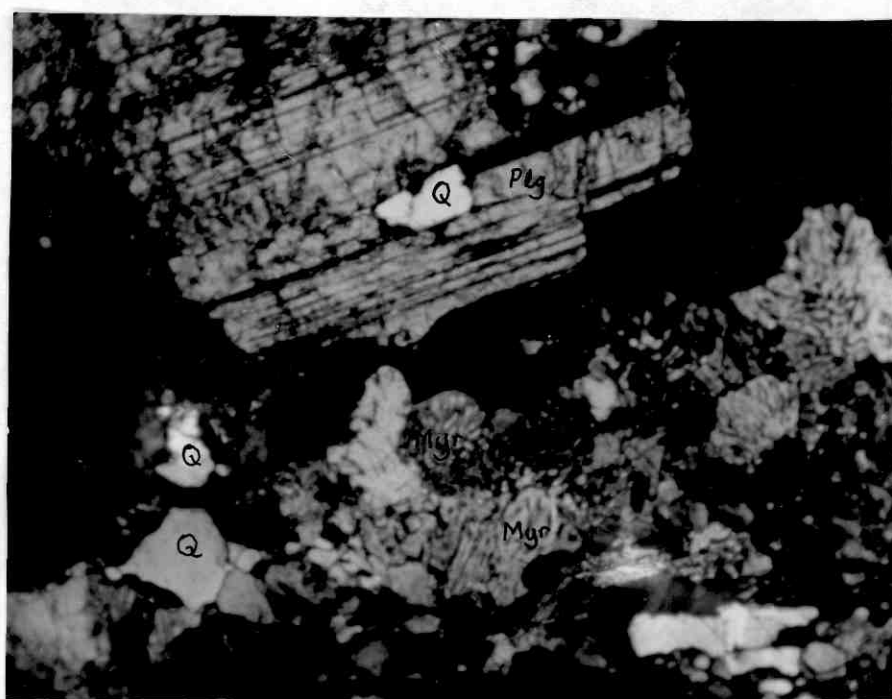


Plate 29. Subangular quartzite enclave with its long axis aligned parallel to the gneiss schistosity. Note the absence of K-feldspar blastesis in the enclave and the alignment of quartzite banding (QB) and external gneissose schistosity (Gnf).

TV 653914

Plate 30. Subrounded quartzite enclave in prophyroblastic gneiss and cut by a thin non-dilational aplitic vein parallel to the gneissic schistosity.



Plate 31. Quartzite groundmass showing irregular microcline, (Mic), developed. Plagioclase is sericitised (Plg). The microcline seems to favour development along quartz grain boundaries.

9FD 824 Crossed nicols (x 112)

Plate 32. Plagioclase blastesis in a quartzite groundmass. The presence of the irregular quartz blebs, Q, and their optical continuity with the quartz outside the crystal indicate that quartz is being replaced. The irregular skeletal margin (arrowed) is also characteristic of blastesis. Patchey sericite is developed and replacement by later microcline is seen to the right. The microcline (MIC) bottom right also shows skeletal development into the quartz groundmass. The plagioclase shows strain extinction and deformed twin planes.

9FD 600 Crossed nicols (x 112)

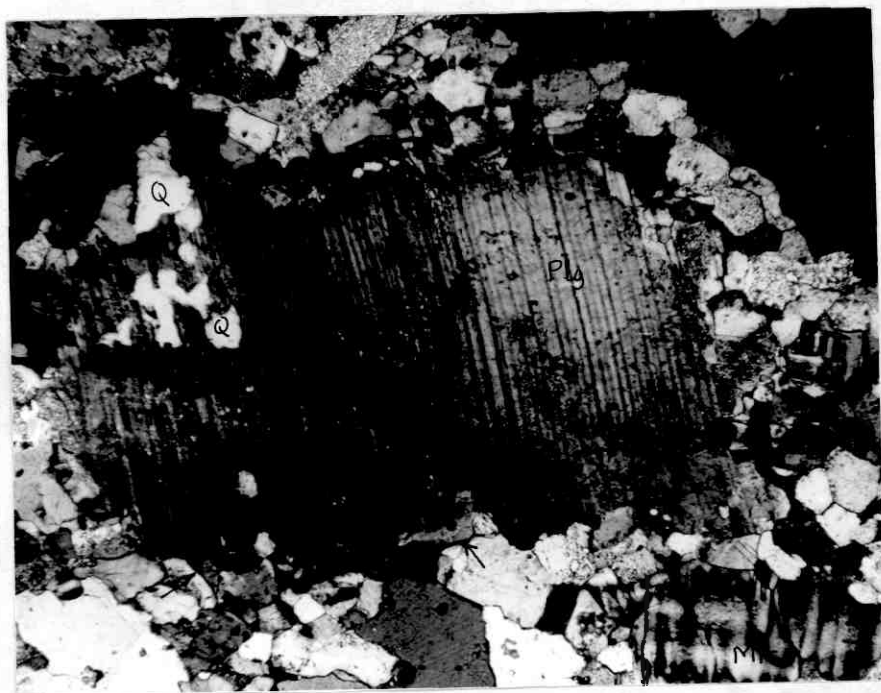
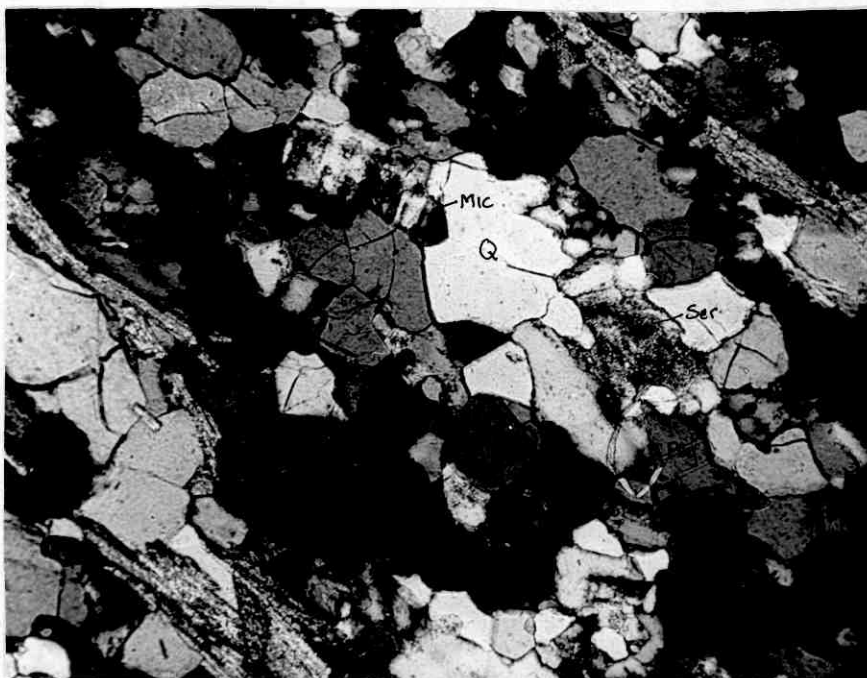


Plate 33. Microclinisation of quartzite groundmass.
The microcline shows skeletal development inclusion of
groundmass quartz.

9FD 824 Crossed nicols (x 256)

Plate 34. Microcline replacing quartz and the biotite
schistosity (Bt) in Lubo Quartzite enclave. The quartz
grain Q_1 is partially replaced, Q_2 is a remnant of the
original grain showing optical continuity with Q_1 . Q_3
is a totally enclosed drop-like quartz inclusion.
Replacement of the biotite foliation is indicated by an
arrow.

9FD 311 Crossed nicols (x 256)

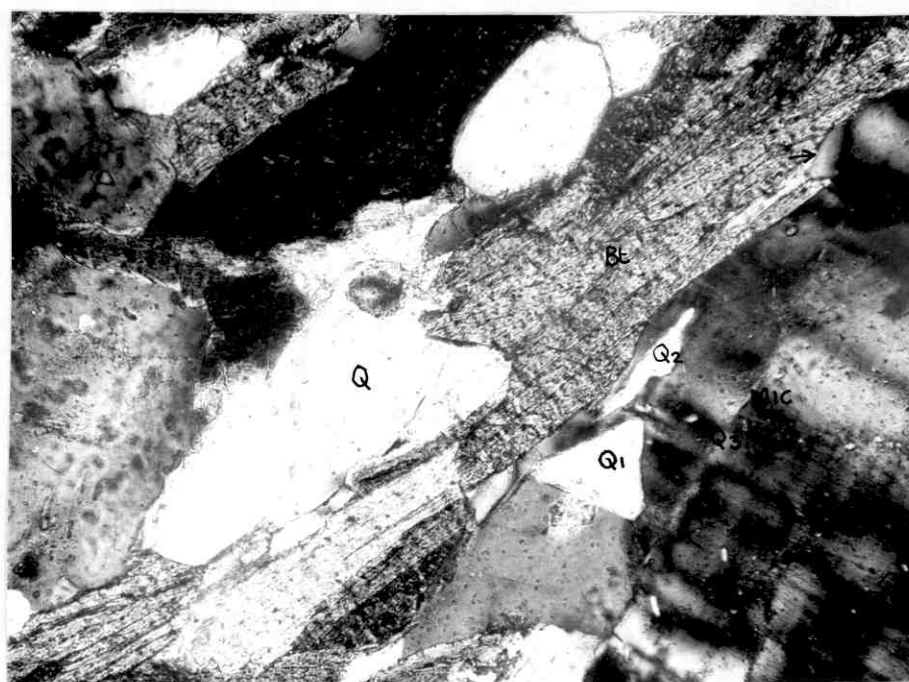
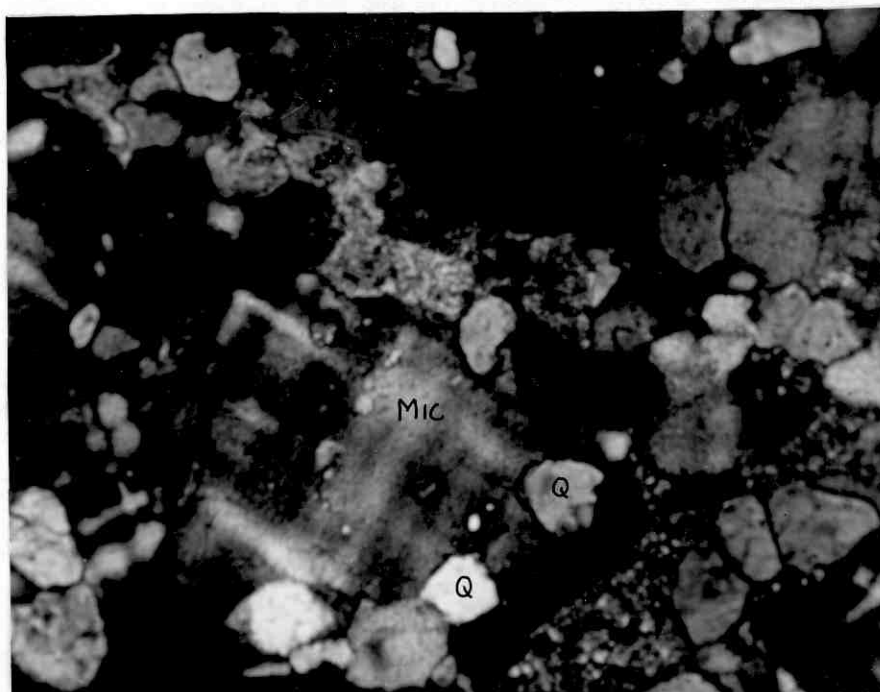


Plate 35. Contact between Nkondo Group Gneiss and a quartzite enclave (Q). Microcline from the gneiss can be seen replacing the quartzite along the contact. Grain boundaries are favoured (arrowed). Small drop-like quartz inclusions (Q) (arrowed) are remnants of the replaced quartz.

9FD 144 Crossed nicols (x 256)

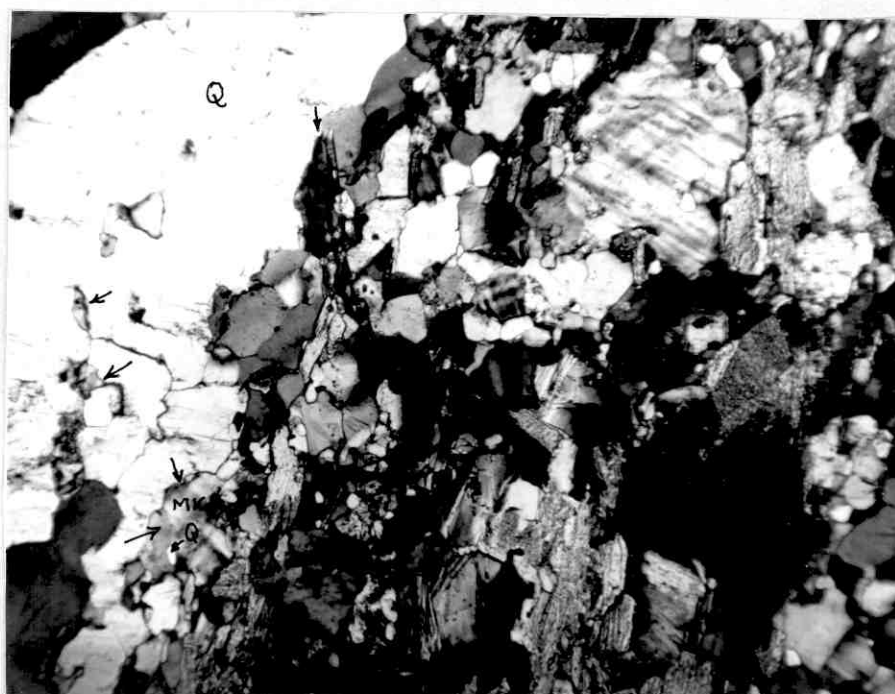


Plate 36. Rounded psammitic enclave (P) which shows corroded margins. Feldspathisation is well advanced with thin aplitic veins, A, originating in the gneiss, occurring along the enclave foliation.

TV 653914

Plate 37. Tabular psammitic enclave (P) showing pre-kinematic relationship to the augen forming foliation. The enclave is cut by a non-dilational aplitic vein, A. No displacement of the enclave is seen on either side of the vein. Offshoots (arrowed) from the vein follow the enclave margin and foliation indicating a path of easy mobilisation.

TV 630871



Plate 38. Microcline (MIC) replacing a psammitic quartz-plagioclase groundmass mosaic. The plagioclase is almost completely sericitised, and sericitic pigments (Ser) occur in the microcline. A clear rim is developed on the plagioclase against microcline. Quartz inclusions, Q, typical of groundmass replacement also occur and the biotite foliation is also included.

9FD 141 Crossed nicols (x 256)

Plate 39. Psammitic groundmass showing plagioclase blastesis (arrows indicate skeletal growth along grain boundaries). The plagioclase is poikiloblastic and includes quartz and biotite.

9FD 141 Crossed nicols (x 256)

Plate 40. Contact between Nkondo Group Gneiss, N, and a psammitic enclave, E₂. The concordance of banding of the two enclaves, E₁ and E₂ and their separation by granitic gneiss indicates² that they probably originated as one individual but have been partially replaced. A late-aplitic vein, A, originates from the granitic gneiss and replaces the enclave. The banding is a direction of preferred replacement.

TV 635864

Place 41. A contact between Nkondo Group, N, and an amphibolite dyke, A. Incipient K-feldspar blastesis is developing in the dyke and a feldspar-rich vein originating from the gneiss is replacing the dyke along its foliation.

TV 655868

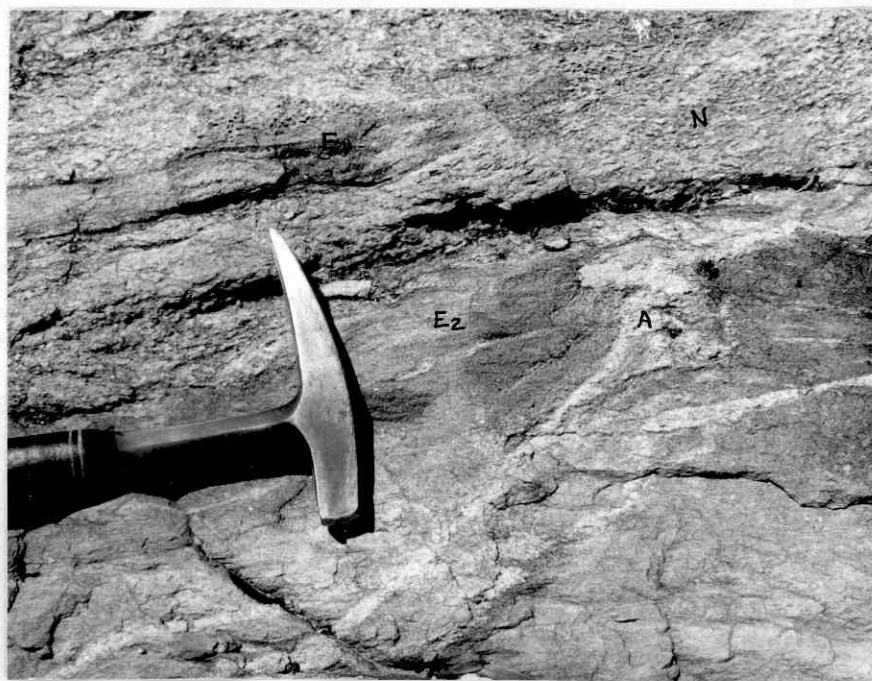


Plate 42. Amphibolite dyke in hornblende gneiss, note the irregular corroded bottom contact and the apparent enclave, E, of hornblende gneiss. The dyke is cut by narrow feldspathic veins originating from the hornblende gneiss.

TV 614860

Plate 43. Enclave of grey fine-grained quartzite, A, in hornblende gneiss.



Plate 44. Amphibolite enclaves, A, preserved as ghostly
relicts in hornblende gneiss.

TV 670870



Plate 45. Replacement of groundmass quartz mosaic by microcline (MIC). The microcline shows a xenoblastic skeletal outline and smaller intergranular grains (arrowed) are also present.

9FD 525 Crossed nicols (x 256)

Plate 46. Replacement of groundmass quartz by microcline. A drop-like quartz, Q, is present.

9FD 528 Crossed nicols (x 256)

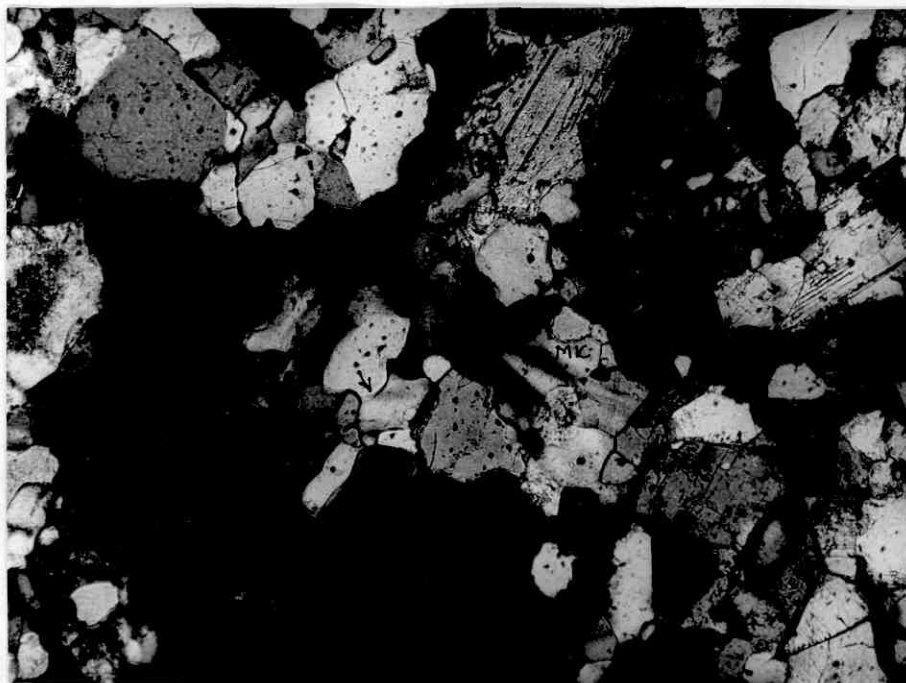


Plate 47. Microcline prophyroblasts (mic) showing pre-schistosity relationship to the quartz-ribbon (Qr). The microcline contains sericitic pigmentation patches representing almost totally replaced plagioclase insets. (Plg). Myrmekite (arrowed) is developing in plagioclase at the grain boundary.

9FD 620 Crossed nicols (x 112)

Plate 48. Corroded plagioclase inset showing a clear rim and sericitic core in microcline. A drop-like quartz inclusion is also present.

9FD 528 Crossed nicols (x 256)

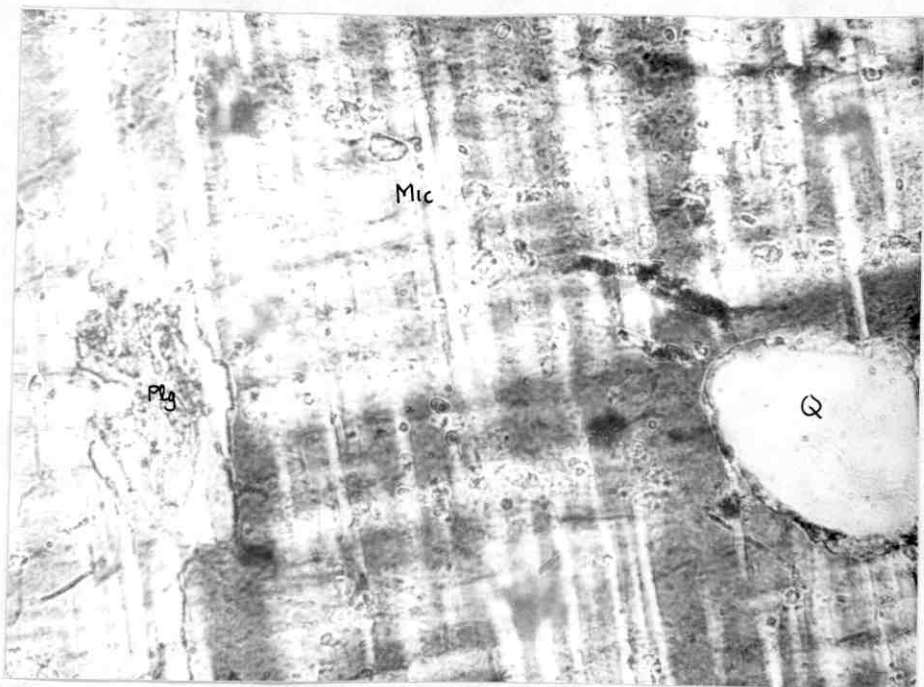
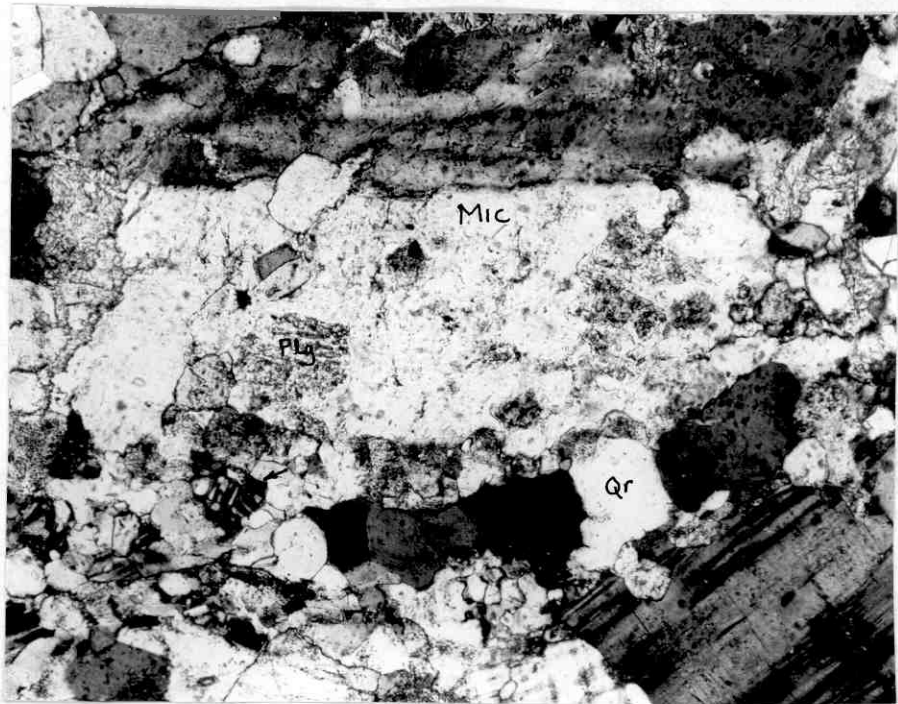


Plate 49. Microcline prophyroblast showing small plagioclase insets with sericitic cores (arrowed); a clear rim is developed at the contact.

9FD 613 Crossed nicols (x 112)

Plate 50. Microcline replacing sericitised plagioclase. An inset has developed at A. Later post-microcline muscovite is replacing the plagioclase and the host microcline (arrowed.)

9FD 573 Crossed nicols (x 256)

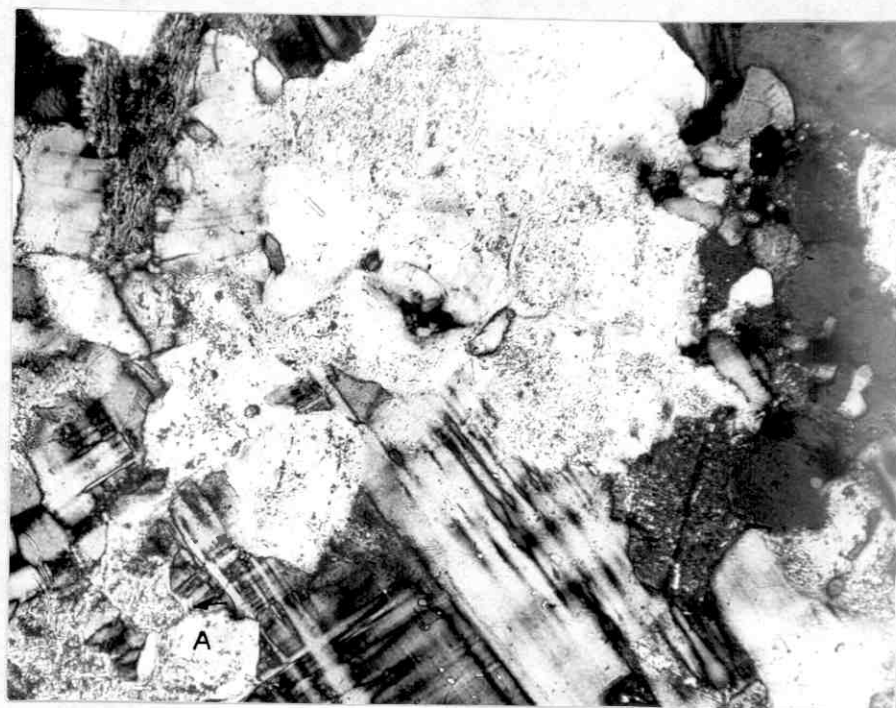
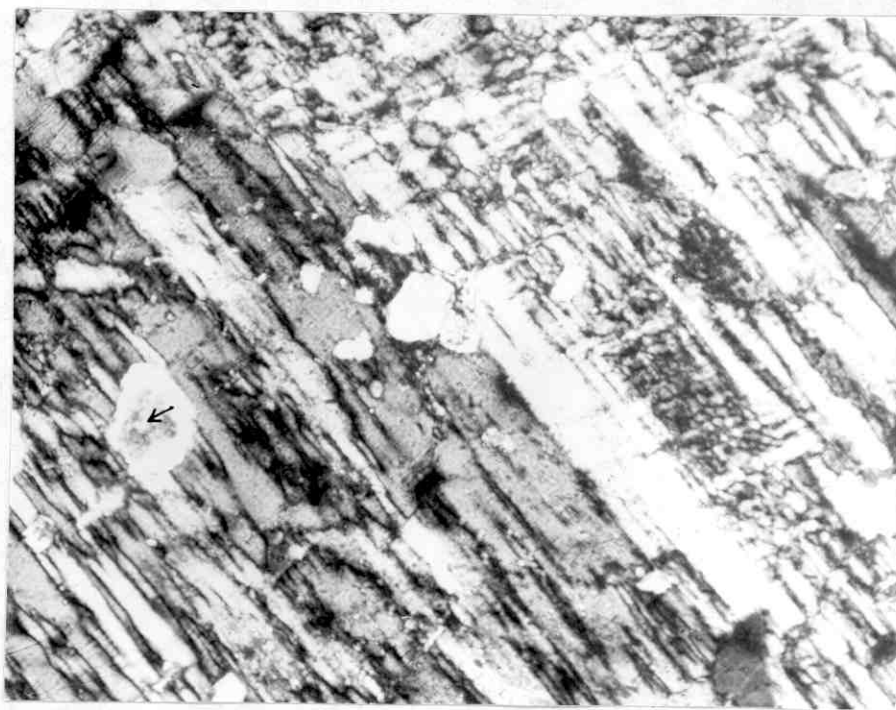


Plate 51. Microcline replacing quartz, Q, at the edge of a quartz-ribbon. Small biotite flake (Bt) is also being included in the microcline.

9FD 795 Crossed nicols (x 256)

Plate 52. Microcline, Mic, replacing plagioclase, myrmekite is developing, (Myr). Note the biotite schistosity composed of polygonised grains forming a lens.

9FD 586 Crossed nicols (x 256)

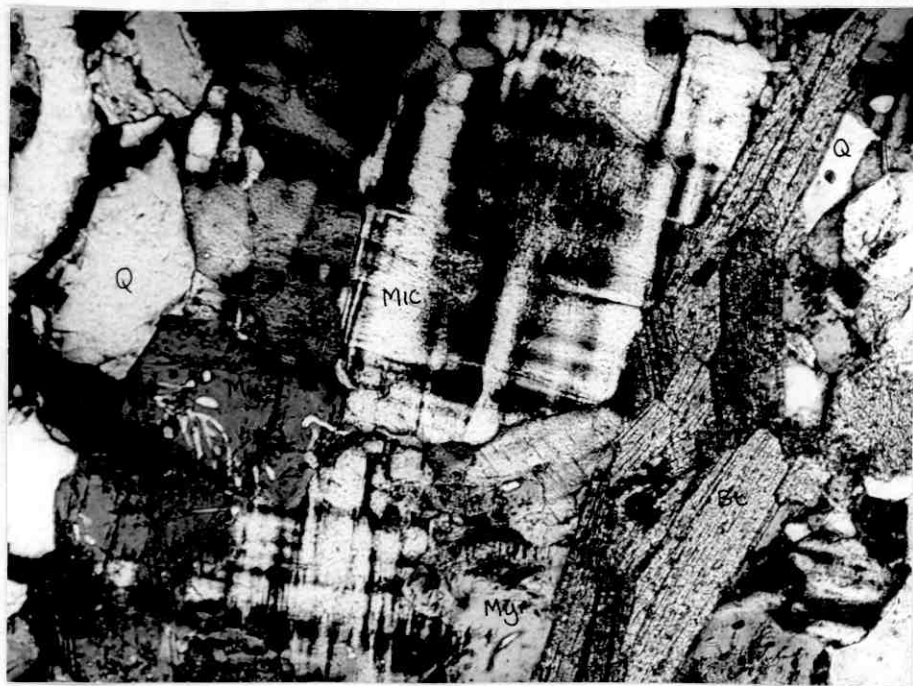


Plate 53. Rounded, sericitised plagioclase insets (Plg) in microcline (Mic). Small drop-like quartz inclusions are also present.

9FD 586 Crossed nicols (x 256)

Plate 54. Microcline (Mic) feldspathising a quartzite groundmass, Q. The microcline can be seen developing along grain boundaries. Rounded, drop-like quartz inclusions are developed in the microcline and indicate incomplete replacement of quartz.

9FD 583 Crossed nicols (x 256)

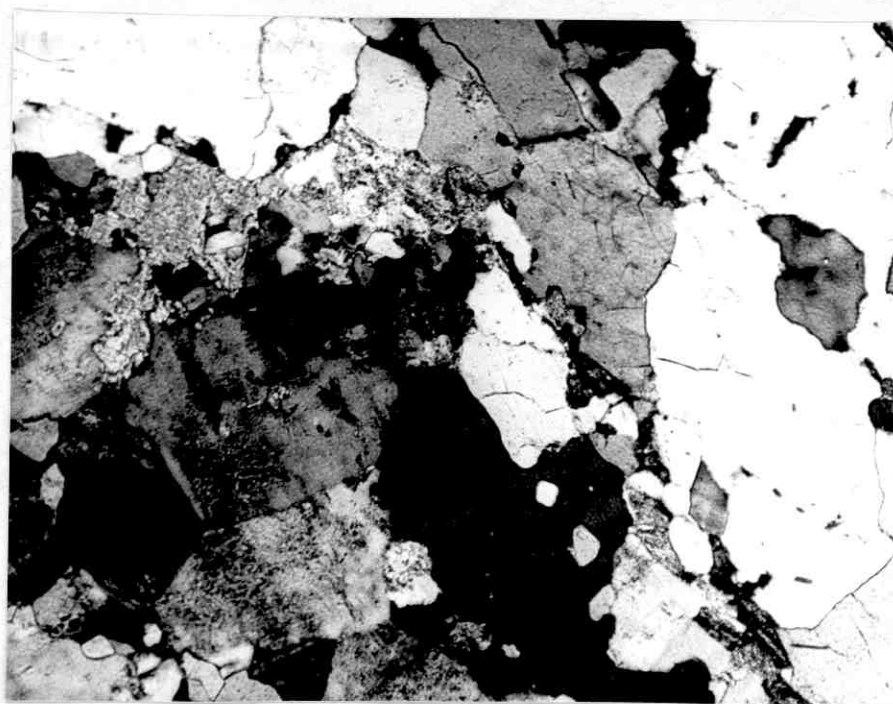
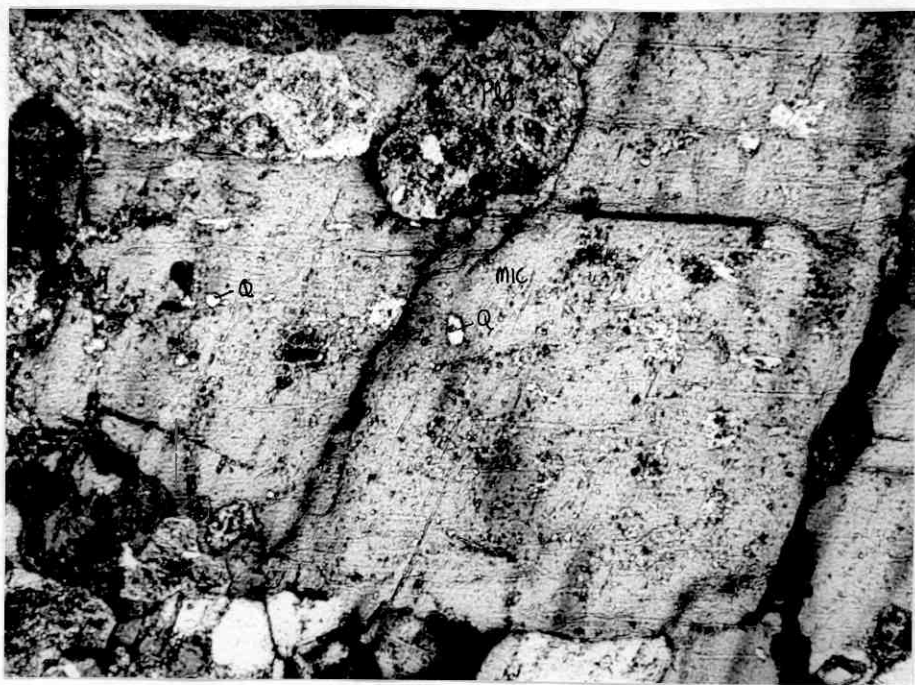


Plate 55. Banded quartzite enclave, A, and psammitic enclave, B, in diatexite gneiss, C. The psammitic shows the development of leucosomes which are folded by F_2 tight folds. F_2 -folding of the diatexite may also be seen.

TV 578878



Plate 56. Banded quartzite, Q, in contact with diatexite gneiss. The quartzite is being transformed by the diatexite. The original extent of the quartzite is indicated by the relict banding, B, and the schlieren of biotite in the diatexite gneiss.

TV 641836

Plate 57. Surmicaceous enclaves in schlieric nebulous diatexite.

TV 673866



Plate 58. Biotite psammite-quartzite band replaced by diatexite gneiss. The intrusive mobile nature of the diatexite is indicated by the disruption of banding in the psammitic band.

TV 688816

Plate 59. Detail of Place 58 showing the disoriented banded biotite psammite enclave indicating the mobility of the enclosing diatexite.

TV 688816

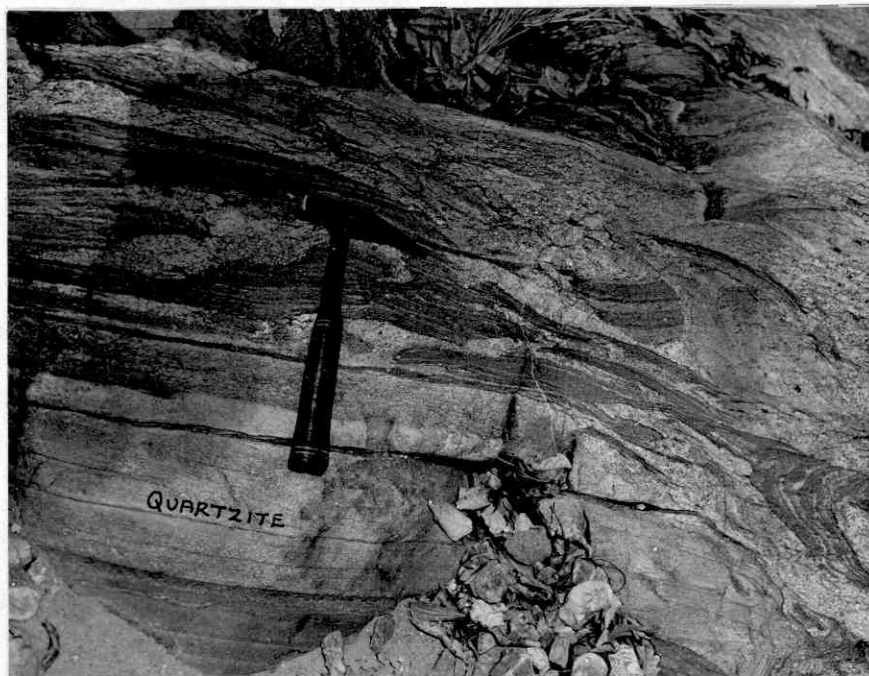


Plate 60. Quartzo-feldspathic segregations showing a muscovite enriched rim in biotite-plagioclase psammite

TV 660800

Plate 61. Schlieric diatexite gneiss with surmicaceous enclaves, B, and relict psammitic enclave, C. A nebulous banding is still apparent by the variation in dark mineral content.

TV 660844



Plate 62. Sericitised plagioclase in a metatexite showing small quartz inclusions and marginal replacement by skeletal microcline (MIC)

9FD 648 Crossed nicols (x72)

Plate 63. Skeletal microcline in the psammitic groundmass of a metatexite.

9FD 648 Crossed nicols (x 72)

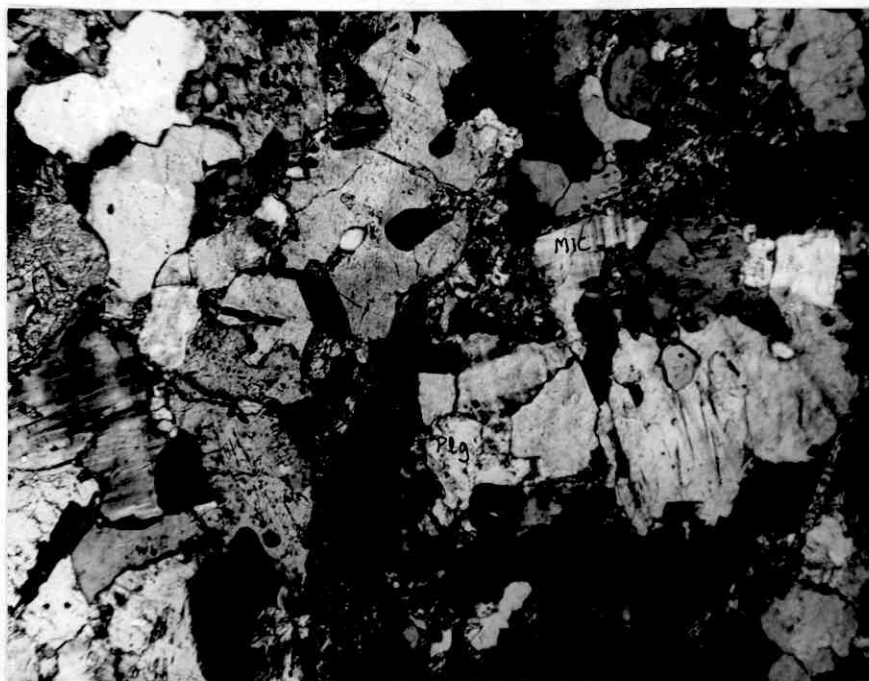


Plate 64. F_2 -folding of banded, biotite psammite and coplanar leucosomes, A. A melanosome developed marginally to the leucosomes is at B. The banding and leucosomes can be traced into the enclosing schlieric diatexite, C. The schlieren are also deformed by F_2 and indicate the pre- D_2 nature of diatexis.

Plate 65. F_2 -folding of nebulous banded diatexite. There has been axial planar growth of biotite in the nose of the fold. Note the surmicaceous enclaves are elongated in this schistosity.

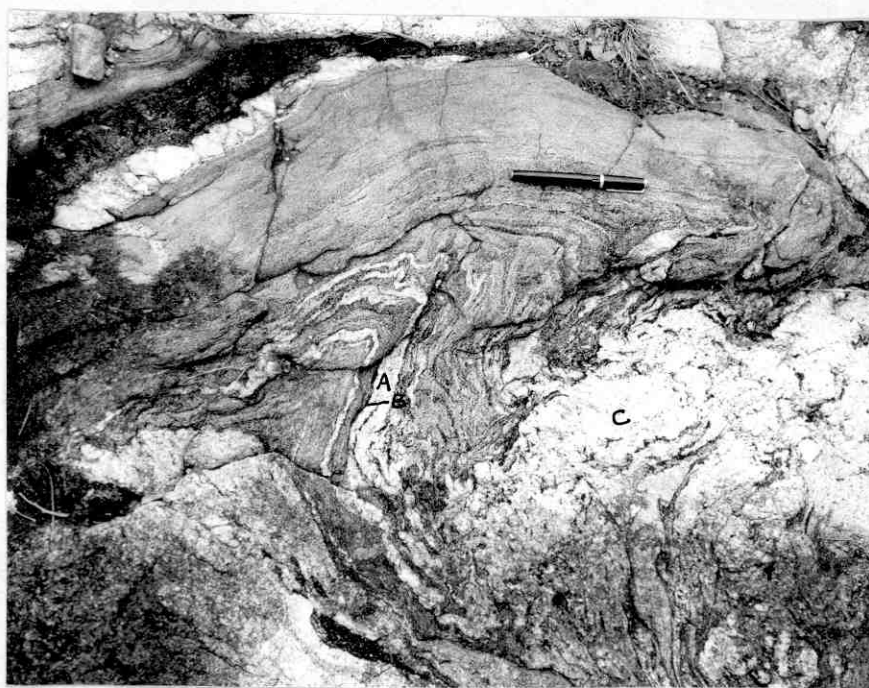


Plate 66. Small scale example of F_2 -folding in diatexite showing a relic biotite -rich banding at A. The biotite shows axial planar growth oriented to later F_3 -folds and is folded around the F_2 -folds indicating pre- D_2 age for the diatexite.

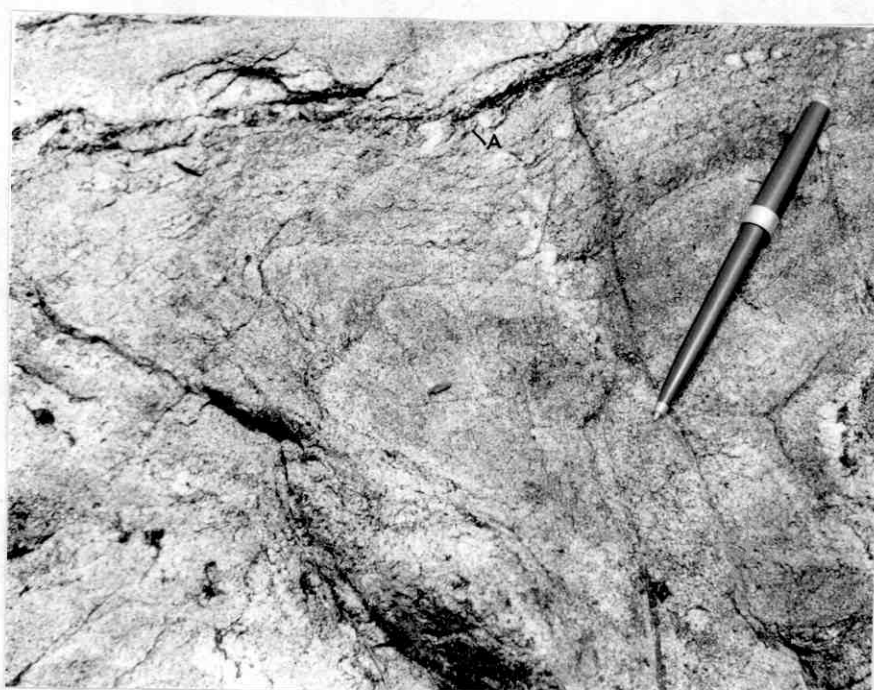


Plate 67. Banded biotite-plagioclase psammite enclave, C, showing a biotite rim, A, in schlieric diatexite, B.

TV 660845

Plate 68. Microcline microperthite (MIC) replacing plagioclase, Plg, showing oriented muscovite inclusions (musc). The initial blastic growth of the plagioclase is indicated by the embayed margins against the quartz groundmass.

9FD 866 Crossed nicols (x 256)

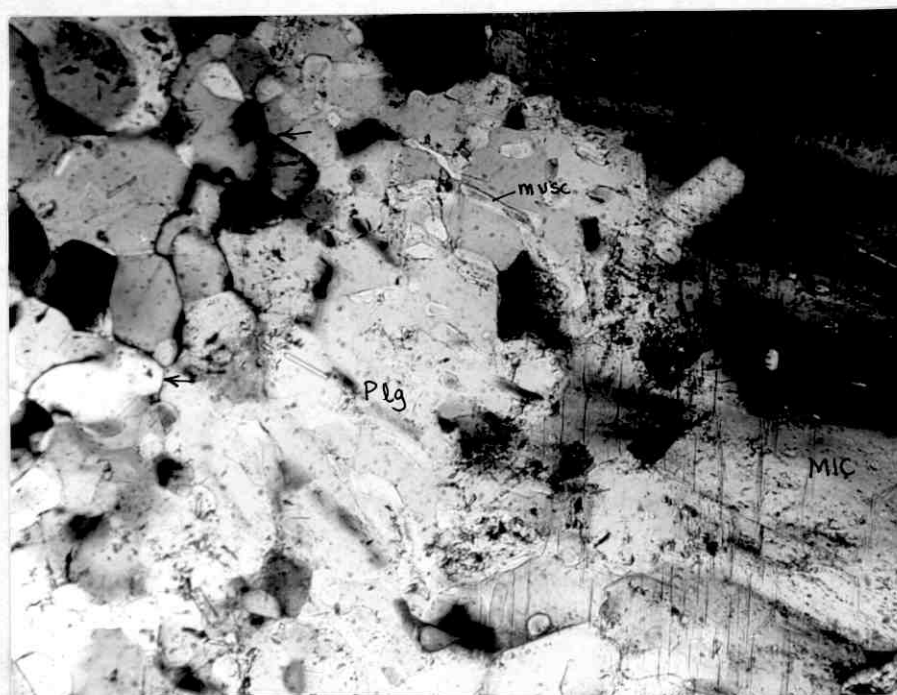


Plate 69. Stromatic banded metatexite, showing well-developed pegmatitic leucosomes with a biotite-rich melanosome. The leucosomes and the original biotite banding of the palaeosome are formed by F_2 -folds. There is axial planar growth of biotite to the F_2 -folds (B)

TV 650857

Plate 70. Outcrop of biotite-plagioclase psammite showing various stages of mobilisation. The original palaeosome, A, is surrounded by a biotite-rich rim, C. The neosome, D, shows a schlieric stromatic structure which in the bottom right of the plate passes into a schlieric diatexite. Both metatexis and diatexis are illustrated.

TV 650857

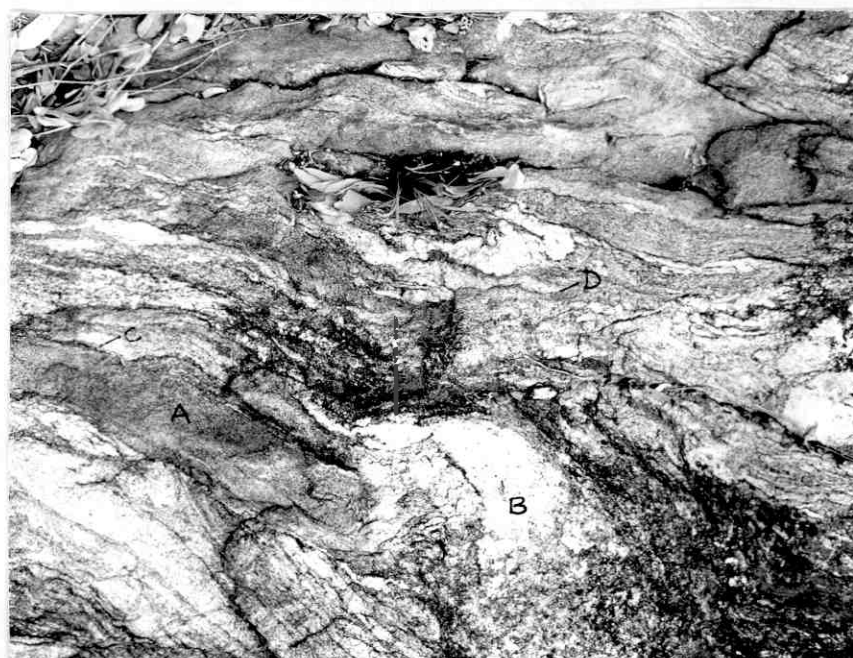


Plate 71. Sericitised plagioclase showing crystallographically oriented secondary muscovite (M) being replaced by later microcline. Plagioclase insets are developing at A and the sericitic pigmentation, B, may be explained as a plagioclase relic. The microcline is also including some of the groundmass quartz as drop-like, inclusions (arrowed).

9FD 684 Crossed nicols (x 112)

Plate 72. Extinction position to show secondary muscovite.

9FD 684 Crossed nicols (x 112)

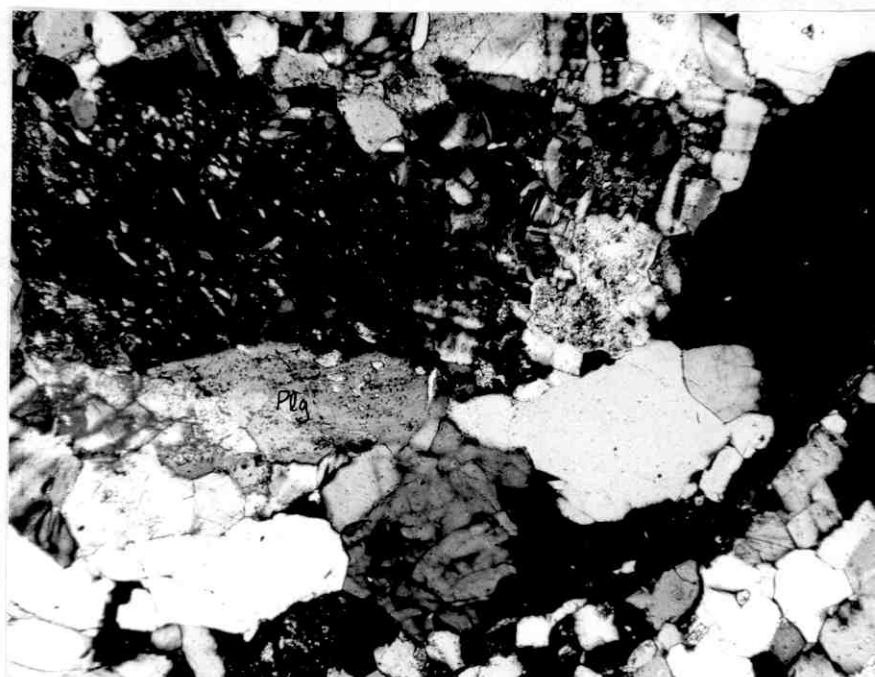
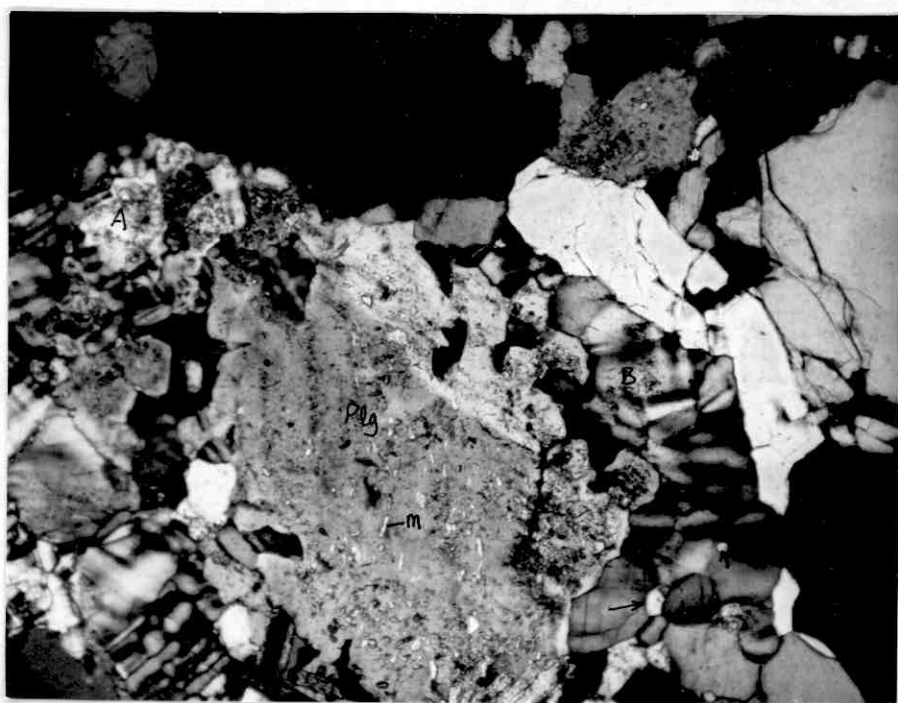


Plate 73. Microcline partially enclosing and replacing (arrowed) an idioblastic, sericitised plagioclase. The plagioclase shows evidence of pre-sericitisation growth into the quartz mosaic of the groundmass (arrowed B), a quartz grain is partially enclosed by plagioclase.

9FD 850 Crossed nicols (x 112)

Plate 74. Part of a microcline porphyroblasts with drop-like quartz inclusions, Q, and saussuritised plagioclase insets. Growth of microcline onto sericitised groundmass plagioclase is arrowed.

9FD 684 Crossed nicols (x112)

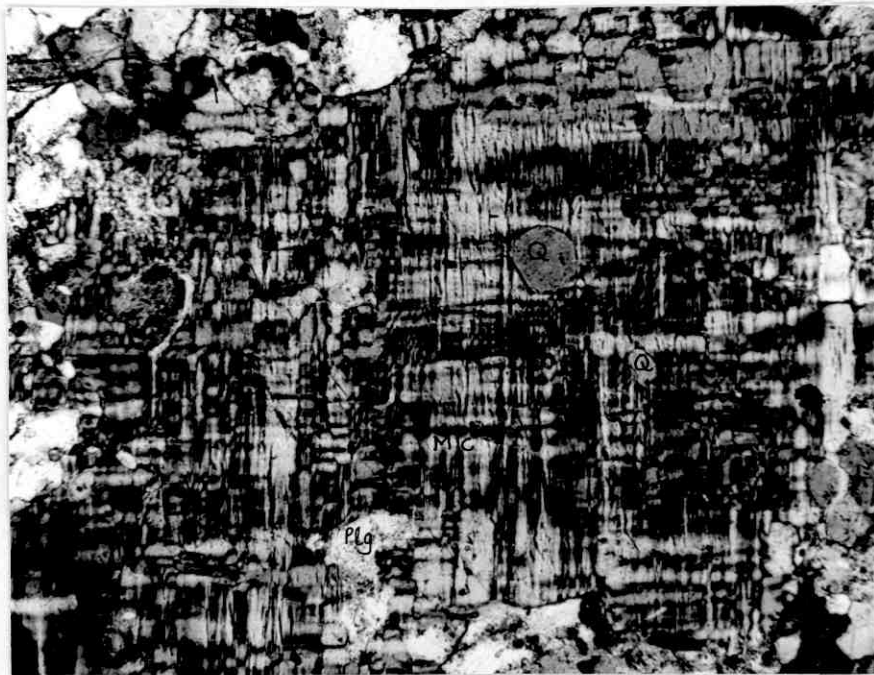


Plate 75. Microcline in the groundmass of a diatexite replacing the quartz mosaic. Sericitised plagioclase provides a site for nucleation. The lobate, penetrating margins of the microcline are typical. Patches of groundmass are preserved in the microcline

9FD 684. Crossed nicols (x 112)

Plate 76. Plagioclase showing blastesis into the quartz groundmass mosaic, including drop-like quartz. A biotite flake (Bt) is also included.

9FD 867 Crossed nicols (x 256)

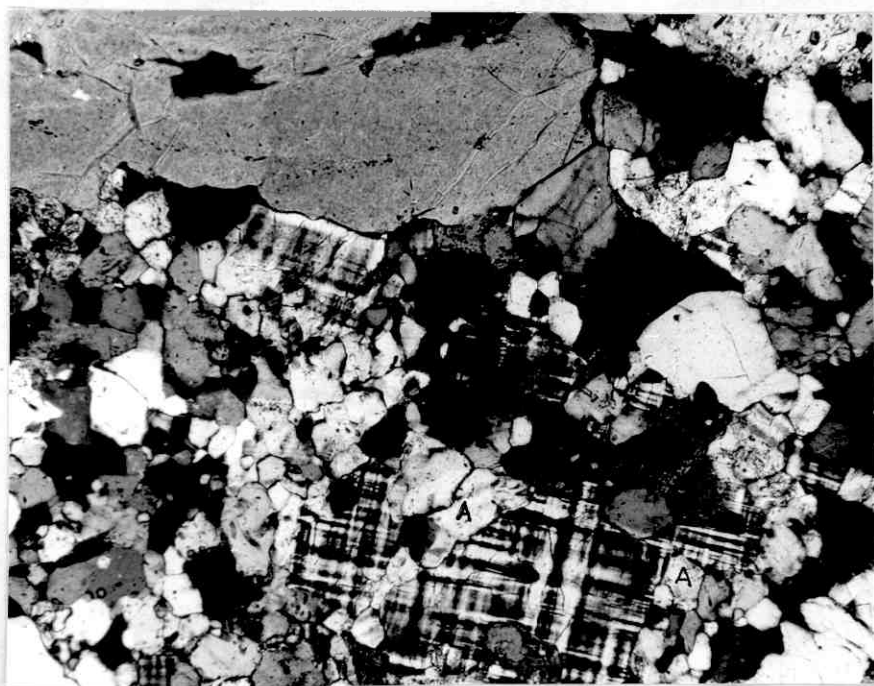


Plate 77. Idioblastic, isometric plagioclase porphyroblast. Shows evidence of blastesis into the quartz groundmass (arrowed). Sericitisation is patchy and secondary muscovite is developed.

9FD 719 Crossed nicols (x 112)

Plate 78. Stromatic banded metatexite cut by diatexite. Note the granular appearance of the diatexite due to the idioblastic plagioclase porphyroblasts. A late vein (V) cuts the contact and it apparently post-dates both groups.

NV 670850

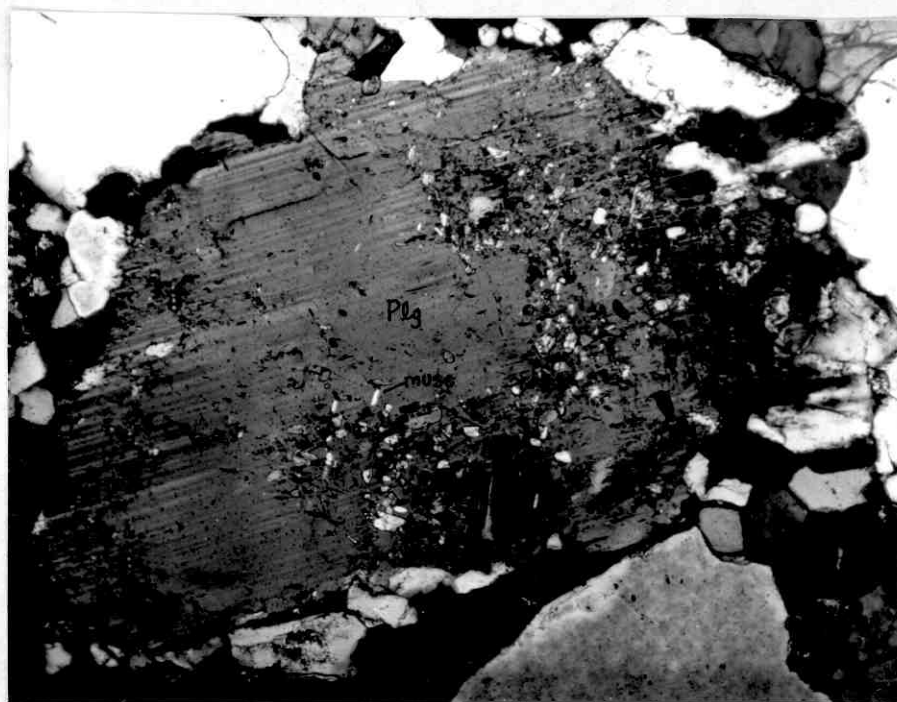


Plate 79. Prophyroclastic K-feldspar in D_2 -tectonised
pegmatitic gneiss. (Grid. ref. 635803) Note the
formation of pseudo-augen (P).

Plate 80. Pegmatite dyke in diatexite gneiss of the
Migmatitic Gneiss Group. The dyke has been sheared
into and disrupted by well-developed NE trending shear
zones (D_2).



Plate 81. Gently F_3 -folded, non-dilational pegmatitic veins, A, with offshoots along metasedimentary banding, B.

Plate 82. Pegmatite dyke on the limb of an F_3 -fold showing evidence of displacement of metasedimentary banding due to marginal shear. Metasomatic emplacement is indicated by the small non-dilational offshoots at the top of the photograph and the intact metasedimentary septa into the dyke, E.

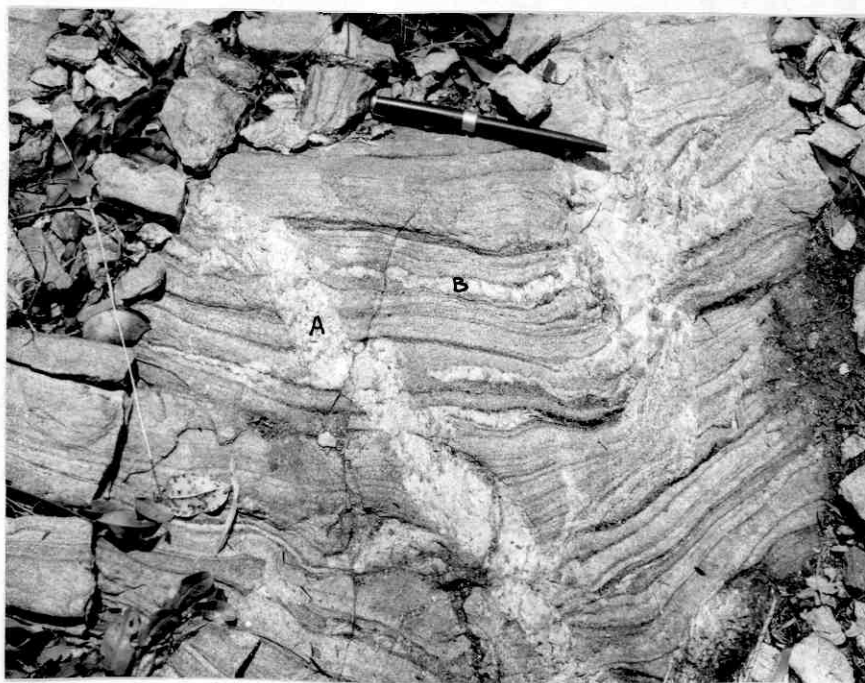


Plate 83. Plagioclase blastesis into a quartz-plagioclase, psammitic mosaic. Drop-like quartz inclusions (q) are included in the plagioclase. Late microcline is replacing the plagioclase and shows optical continuity through the plagioclase blast. Small plagioclase insets (arrowed) occur in the microcline.

9FD 797 Crossed nicols (x 112)

Plate 84. Microcline replacing plagioclase (Plg) along pre-existing cracks (arrowed) from outside the porphyroblast. The microcline throughout the plagioclase is in optical continuity.

9FD 635 Crossed nicols (x 112)

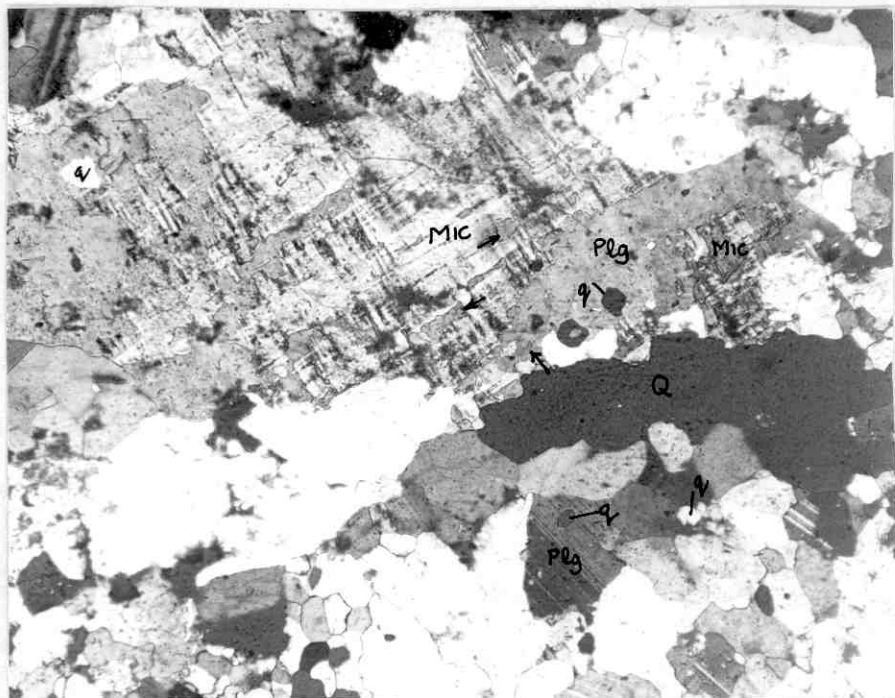


Plate 85. Plagioclase blastesis into a quartz mosaic. Muscovite inclusions occur in two directions of preferred orientation. Note the polygonised quartz-ribbon curving around the plagioclase.

910 797 Crossed nicols (x 112)

Plate 86. Plagioclase blastesis into a quartz-rich groundmass. Blastesis occurs along quartz grain boundaries (arrowed) with the resulting inclusion of some quartz (Q) into the crystal.

910 797 Crossed nicols (x 64)

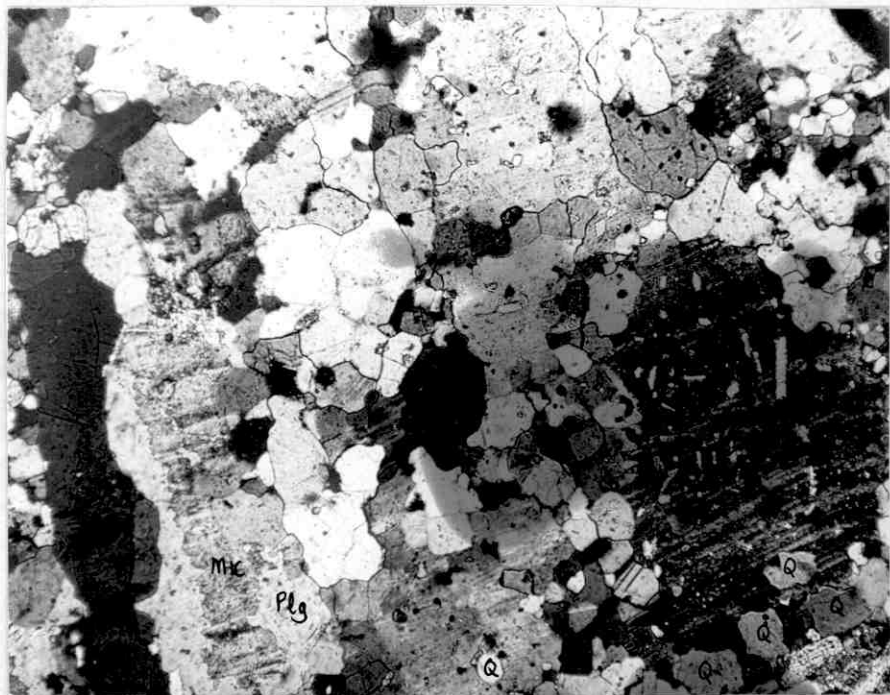
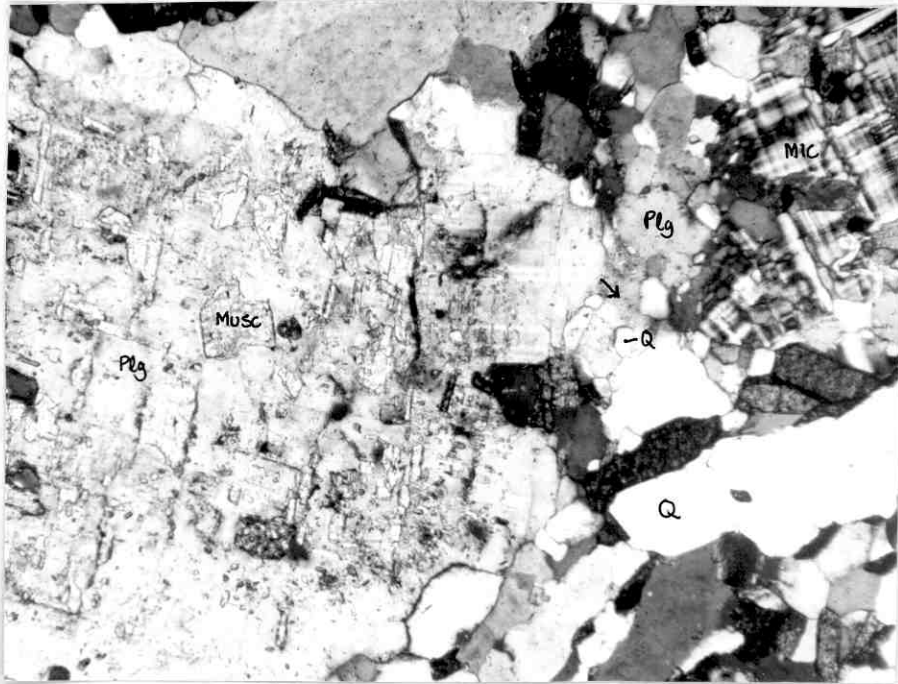


Plate 87. Microcline growing along quartz grain boundaries (arrowed).

9FD 583 Crossed nicols (x 256)



Plate 88. Irumide phase (D_3) crenulation of Nkondo Group
prophyroblastic gneiss. The prophyroblasts are locally
crenulated and a strain slip cleavage is developed.



APPENDIX 1

The geological map of the Chisomo quarter degree sheet (back pocket) shows slight discrepancies in geological boundaries with Fig. 2. This is because Fig. 2 was compiled from more comprehensive field data not available at the time the reconnaissance map was drawn up. The Mwila Gneiss Group was originally considered to be two subgroups, subsequent comparison of chemical analyses, Fig. 4, indicates this subdivision to be unjustified on chemical grounds.

APPENDIX 2

The following chemical analyses are representative of the main gneissose groups described in the text. Analysis was carried out by X.R.F. spectrometry on fused lithium tetraborate discs. FeO was determined by a wet chemical method. U.S.G.S. standards were used as internal standards.

A complete record of chemical data obtained during this study is held by the Geological Survey Department, Lusaka, Zambia.

MWILA GNEISS GROUP - Late-kinematic granitic gneiss

	9FD 530	9FD 546	9FD 572	9FD 574	9FD 621	9FD 679	9FD 681	9FD 642
SiO ₂	70.84	73.38	72.38	74.54	70.23	73.34	72.56	73.51
TiO ₂	0.22	0.18	0.23	0.17	0.38	0.24	0.17	0.12
Al ₂ O ₃	15.12	13.85	14.02	14.38	14.62	14.37	14.13	13.37
Fe ₂ O ₃	0.74	0.54	0.61	0.59	1.89	1.08	0.83	0.17
FeO	0.93	0.68	1.22	1.01	1.22	1.08	0.58	0.86
MnO	0.05	0.05	0.05	0.04	0.04	0.06	0.04	0.05
MgO	0.36	0.08	0.23	0.17	0.34	0.42	0.04	0.68
CaO	1.18	0.86	1.14	0.79	1.57	1.05	1.07	1.17
Na ₂ O	2.81	2.50	3.24	2.81	2.52	3.61	3.77	3.33
K ₂ O	5.80	5.83	4.94	5.41	5.03	5.45	5.56	4.69
P ₂ O ₅	0.16	0.17	0.11	0.04	0.09	0.17	0.16	0.13

	9FD 530	9FD 546	9FD 572	9FD 574	9FD 621	9FD 679	9FD 681	9FD 642
<u>NORMS</u> (calculated water-free)								
Q	29.84	35.43	32.07	35.14	33.33	28.47	27.67	33.06
C	2.50	2.31	1.56	2.56	2.44	1.02	0.35	1.02
Or	34.90	35.11	29.74	31.99	30.35	31.93	33.22	28.26
Ab	24.21	21.56	27.93	23.79	21.77	30.28	32.25	28.73
An	4.90	3.22	5.03	3.66	7.35	4.06	4.31	5.05
Opx	1.75	0.81	2.06	1.58	0.99	1.84	0.27	3.09
Mg	1.09	0.80	0.90	0.86	2.80	1.55	1.22	0.25
Il	0.43	0.35	0.44	0.32	0.74	0.45	0.33	0.23
Ap	0.38	0.40	0.26	0.09	0.21	0.39	0.38	0.31

GNEISSOSE MWILA GRANITE

	9FD 586	9FD 587	9FD 588	9FD 617	9FD 624
SiO ₂	73.49	76.86	72.98	73.52	75.43
TiO ₂	0.37	0.07	0.26	0.15	0.10
Al ₂ O ₃	14.33	13.47	14.72	14.77	13.75
Fe ₂ O ₃	0.32	0.29	0.68	0.71	1.37
FeO	0.68	0.43	1.29	0.72	0.36
MnO	0.04	0.01	0.04	0.03	0.02
MgO	0.00	0.00	0.24	0.23	0.05
CaO	0.71	0.66	1.33	0.86	0.50
Na ₂ O	3.40	3.58	2.46	3.39	2.42
K ₂ O	4.81	4.73	5.14	5.54	5.45
P ₂ O ₅	0.11	0.18	0.22	0.16	0.13

	9FD 586	9FD 587	9FD 588	9FD 617	9FD 624
<u>NORMS</u> (calculated water-free)					
Q	34.48	36.71	35.98	30.59	39.88
C	2.55	1.69	3.24	2.01	3.29
Or	28.93	27.87	30.57	32.71	32.34
Ab	29.28	30.21	20.95	28.66	20.56
An	2.85	2.09	5.19	3.22	1.64
Opx	0.46	0.45	2.06	1.11	0.13
Mg	0.47	0.42	0.99	1.03	0.94
Il	0.72	0.13	0.50	0.28	0.19
Ap	0.26	0.42	0.52	0.37	0.30
Hem.	-	-	-	-	0.73

MIGMATITIC GRANITE GNEISS - diatexites						NKONSOLO GROUP - plagioclase blastite			
	9FD 670-1	9FD 681	9FD 683	9FD 684	9FD 695	9FD 560	9FD 561	9FD 559	9FD 556
SiO ₂	73.65	72.56	76.22	73.91	75.06	63.41	66.48	65.66	68.25
TiO ₂	0.16	0.17	0.22	0.20	0.12	1.19	0.92	1.08	0.64
Al ₂ O ₃	14.01	14.13	11.75	14.19	14.21	13.45	15.90	15.21	14.62
Fe ₂ O ₃	0.92	0.83	0.56	0.69	0.90	3.72	2.54	2.36	2.09
FeO	0.57	0.58	1.08	0.93	0.36	1.33	3.52	4.38	2.44
MnO	0.09	0.04	0.05	0.01	0.03	0.08	0.09	0.10	0.06
MgO	0.29	0.04	0.67	0.13	0.00	1.89	0.87	1.60	1.06
CaO	1.13	1.07	1.35	0.98	1.04	2.04	2.25	3.15	2.32
Na ₂ O	3.72	3.77	3.37	2.65	2.96	3.26	2.25	3.14	3.43
K ₂ O	5.45	5.56	4.47	5.39	3.99	2.92	3.53	2.94	4.09
P ₂ O ₅	0.09	0.16	0.16	0.11	0.04	0.17	0.30	0.34	0.17

NKCNDU GROUP - Syn-kinematic Granitic Gneiss

	9FD 564	9FD 618	9FD 628	9FD 629	9FD 659	9FD 671
SiO ₂	74.07	69.75	70.99	67.16	68.04	68.32
TiO ₂	0.25	0.67	0.59	0.94	0.72	0.84
Al ₂ O ₃	14.12	13.02	13.17	14.41	14.46	14.13
Fe ₂ O ₃	0.75	1.99	1.74	2.22	1.37	2.04
FeO	1.15	3.23	2.91	3.31	2.95	3.02
MnO	0.05	0.08	0.01	0.09	0.22	0.21
MgO	1.11	0.62	0.81	1.06	1.03	1.14
CaO	1.00	2.01	1.86	1.77	2.75	2.40
Na ₂ O	3.72	2.00	2.37	3.45	3.57	3.10
K ₂ O	4.59	4.08	4.00	4.18	2.82	3.65
P ₂ O ₅	0.14	0.17	0.18	0.19	0.22	0.21

APPENDIX 3

Lithostratigraphic Terms

Lufuba Group (Gray 1929) 'Partly injection gneisses and partly fine-grained amphibolite schists. The rocks exposed are so thoroughly deformed and recrystallised that original characteristics are completely obliterated'.

Muva (Reeve 1963, p 18) A thick alternating sequence of psammitic and pelitic metasediments. Quartzites are the predominant psammities and define northeasterly trending ridges, a characteristic of the Irumide Fold Belt.

Irumi Formation (Stillman 1965, p 17) Schists predominate and contain quartzite horizons from a few feet to several hundred feet thick.

Musofu Formation (Stillman 1965, p 22) An alternating succession of schists and quartzites. At the base a considerable thickness of pebbly quartzite contains lens shaped masses of conglomerate which grade laterally to current bedded, slightly pebbly quartzite. The quartzites higher in the sequence show strong cross bedding and form ridges.

Kalonga Formation (Stillman 1965, p 26) A mixed low grade sequence of phyllites, metasilstones, pure quartzites and sericitic quartzite.

APPENDIX 4Glossary of migmatite terminology

Anatexis	melting of rock
Diatexis	high grade anatexis which includes the mafic minerals.
Feldspathisation	Metasomatic crystallisation of feldspar.
Granitisation	Process involving addition and removal of rock components by which pre-existing solid rocks of any composition and origin are transformed into granite.
Leucosome	Leucocratic part of a migmatite, generally rich in quartz and feldspar.
Melanosome	Meleocratic part of a migmatite, rich in mafic minerals.
Metatexis	Partial, differential or selective anatexis of low melting components of a rock (generally quartz and feldspar).
Nebulite	Migmatite with ghost-like relics of pre-existing rocks.
Neosome	Newly formed part of a migmatite.
Palaeosome	Parent rock of a migmatite
Palingenesis	Formation of a new magma by melting of pre-existing rocks.
Restite	Geochemically immobile part of a rock during partial mobilisation of rock components.

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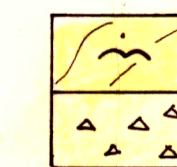
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THE GEOLOGY OF THE CHISOMO AREA.

SHEET 1330SE

BY B.A. KLINCK B.Sc. (SpHons), F.G.S.

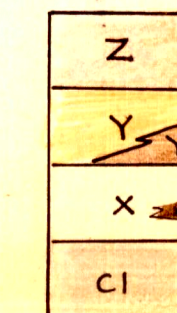
KEY



TERRACED ALLUVIAL DEPOSITS
LATERISED QUARTZITE BRECCIA.

RECENT

UNCONFORMITY

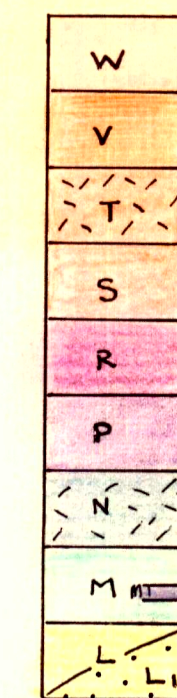


Z CY SSTS & MUDSTONES
* Rp - Fossil Reptiles.
Y RED COARSE X-BEDDED FELD. SSTS
WITH FINE GRAINED INTERBEDDED
SST & MUDSTN LOCALLY (Yv).
X CY MUDSTNS WITH THIN HARD CALC
SSTS (Xv), ABUNDANT CALC NODULES LOCALLY.
CI CY MUDSTN WITH THIN COALS & THIN SSTS.

NTWEWE FM
ESCAPMENT GRIT
MADUMABISA MUDSTONE

KARROO

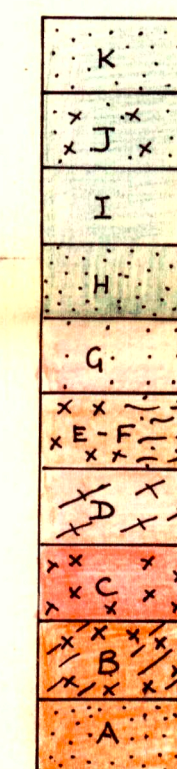
FAULTED UNCONFORMITY



W PEGMATISED METASEDIMENTS, BANDIED
MICMATITES & PSAMMITIC GRANITE GNS.
V Bt. K FELD PORPHYROBLASTIC GNS.
T LEUCO-PORPHYROBLASTIC GRANITE GNS.
S GRANITE GNS.
R BANDIED MICMATITE
P BANDIED FELDSPATHISED PSAMMITES
& PELITES
N CALC. SILICATE
M METASEDIMENTS, Bt. musc schists
with thin marble-calc silicates (M₁)
L Metagraywackes, L₁ Sambiya, L₂ Mpyushe
L₃ Lubo (L₁ coarse granular) L₁, L₂, L₃
fine-mad gnd, micaceous.

CHIBAMBILA GROUP
NKONDO GROUP
MWILA GNEISS GROUP
MTIMBE GROUP
NKONSOLO GROUP
MILILO SUPERGROUP

BASEMENT



K Amphibolite
J Fine grained porphyritic clarkite
I Gabbro
H Hornblende
G Migmatitic Granite Gns.
F Nakasolo Syenite
E Mwila Granite
D Kambowé Adamellite
C Lukangaba Granite
B Barr Granite.

INTRUSIVES
&
ANATECTIC
GRANITOIDS.

M.O. 57

GUERNSEY MINERAL OCCURRENCE
Asbestos
Coal
Fluorite
Gold



F Foliation
R Refoliation
S Strain slip cleavage
J Joint
A Axial plane
B Budding
M minor fold axis
L minor fold with dip of limbs
T foliation with rodding/minor lineation
foliation with exfoliation lineation.

Trend seen on air photograph

Geological boundary inferred.

Geological boundary transitional.

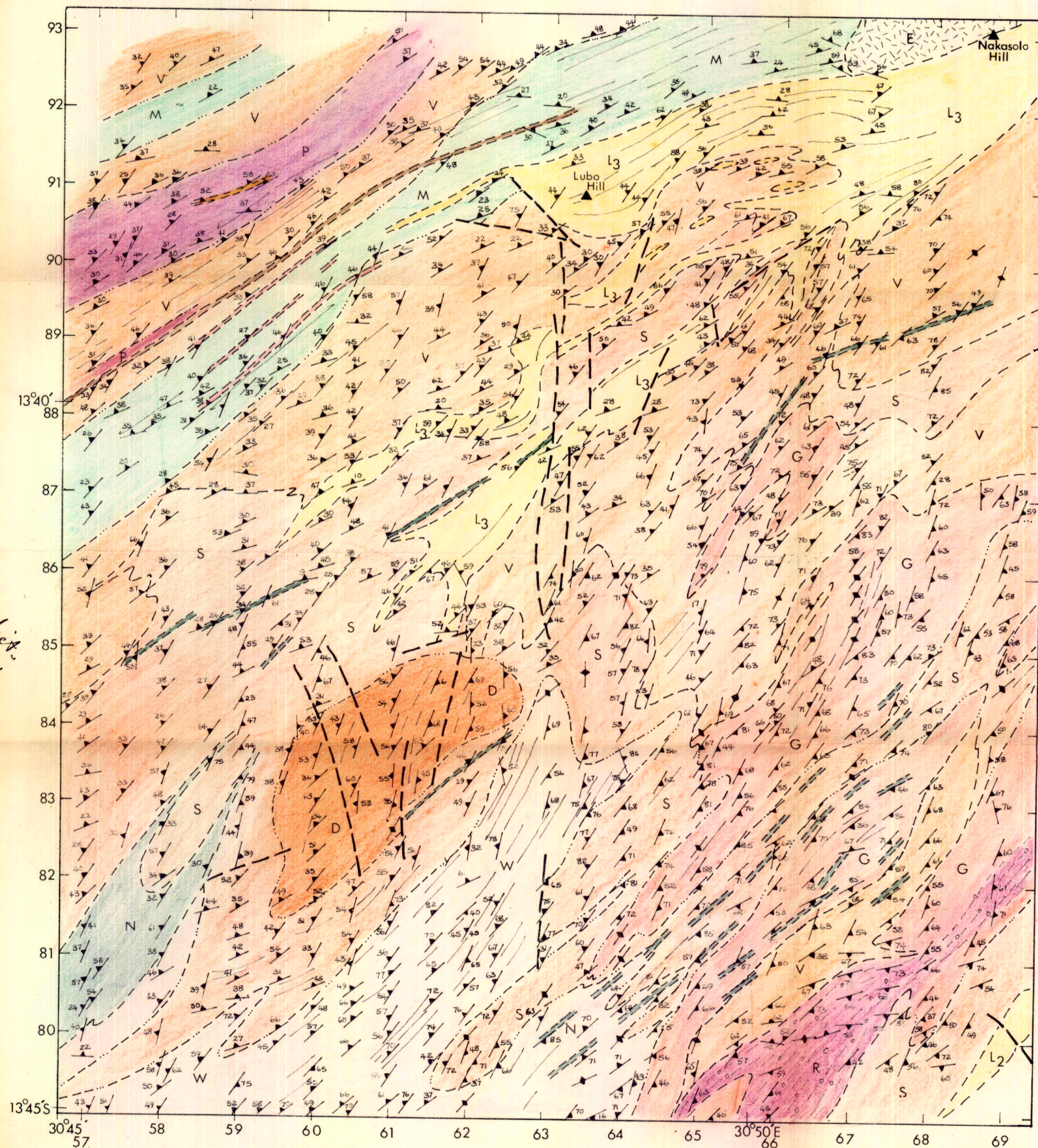
Fault, disconformity indicated

Unconformity inferred.

NOTE: The area outlined in solid black is the Chisomo Area represented by Figure 2. The reader will note that there are differences in geological boundaries. This is because Figure 2 was drawn after the initial mapping and is a reinterpretation based on more extensive field data.

The Geology Of Part Of The Chisomo Area, Zambia.

Fig 2



KEY

P	Nkonsolo Group	} MILILO SUPERGROUP
M	Biotite Schist Group	
N	Calc Silicate Group	
L ₃	Lubo Quartzite Group	

W	Chibambila Group
S	Mwila Gneiss Group
D	Gneissose Mwila Granite D
G	Migmatitic Gneiss Group
R	with metatexites R
V	Nkondo Group

- amphibolite
- aplite
- air photo trends
- inferred geological boundary
- inferred transitional geological boundary
- inferred fault
- dip and strike of foliation
- vertical dip with strike

Scale 1:50,000

