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Thesis

Submitted for the Degree of Doctor of Philosophy

In the University of Durham.

The Petrology of The Older Granites

Around Bauchi, Nigeria,

by

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Hatfield College

and

The Department of Geology

Durham Colleges.

Durham.

June, 1959

THE PETROLOGY OF THE OLDER GRANITE AROUND BAUCHI

NIGERIA

ERRATA

Page 10 line 12 for abundance and soon, read abundance and th the rock soon.

Page 21 line 17 for clacsilicate, read calcslicate.

Page 23 line 8 for grantie, read granite.

Page 150 line 13 for euqilibrium, read equilibrium.

Page 163 line 5 for filed, read field; line 12 for underformed, redd undeformed.

Page 164 line 12 for discontnuos, read discontinuous.

line 19 for seperated, read separated.

Page 175 line 12 for fluorine, read fluorite.

Page 192 last line for fig 21, read fig 19.

The Bauchi district is characterised by isolated
groups of hills and inselbergs seperated by wide,
flat-lying plains which are actually low domes. The
picture is taken from one of these domes just south
of Gurn hill looking southwards. The hills to the
right are the lower members of the Kasuma hills, and
on the horizon the Baskin hills are just discernible.
The isolated hill in the centre is Runde hill, an
inselberg; to the extreme left on the horizon are the
Jura hills.

PREFACE

The investigation which is the subject of this thesis was carried out in the Department of Geology, Durham Colleges in the University of Durham, under Professor K. C. Dunham, F.R.S. During the first year the work was supervised by R. Phillips, B. Sc., and subsequently by C. H. Emeleus, D. Phil.

The writer is indebted to Professor Dunham for giving him the opportunity to do this research work under him, and for much assistance and encouragement.

Gratitude is expressed to the staff and research students in the Department of Geology for kindness and useful discussions, particularly to;

Dr. Emeleus and Mr. Phillips without whose closest cooperation, and guidance at all stages, the work would have been impossible;

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Mr. J. Cobbing for reading critically some of the manuscript, and jointly with Mr. W. Layton for one of the chemical analyses in this account;

Mr. R. P. Hollingworth who has carried out most of the chemical analyses in the report;

I am much indebted to Professor F. H. Rhodes for suggesting the Durham Colleges for this research work,

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The writer is further indebted to the Director and staff of the Geological Survey of Nigeria for their assistance and cooperation during the two periods of field work in Nigeria; to Professor C. D. Campbell, Professor M. Vuagnatt and Professor F. H. Stewart for their suggestions on various problems; to the Master and Tutors of Hatfield College, Durham Colleges for their help in many ways, and to the secretarial office staff of the Science Laboratories, Durham Colleges for various assistance with correspondence throughout the period of study.

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Mr. B. O. Adepoju and Mr. F. Dalley extended much kindness and hospitallity to me while I was in Bauchi during the field investigation; Mrs. F. M. Diesman rendered some financial help; Mrs. M. Bainbridge, Miss O. Williams and Miss E. Norman helped with typing during the preparation of this account. All these are gratefully acknowledged.

III

The Petrology of the Older Granites
around Bauchi, Nigeria

Abstract.

The area studied is situated in the North East
of Nigeria and consists of a rock complex known as the
Older Granites to differentiate it from the granites
of the ring – dyke complexes, termed the Younger
Granites. The rocks in the district are classified
as metasediments, migmatites, Biotite Granite, Biotite
Hornblende Granite, Fayalite Quartz Monzonite and
Quartz Diorite.

In the field the rocks were examined in detail
and a geological map of the area constructed. The
contact relationships of the members of the Older
Granites are described and results of detailed
petrographical examination given. In particular, a
study has been made of the microstructures, including
perthite and myrmekite; from various considerations
the microstructure appear to indicate a metasomatic
origin for large microcline crystals found in these
rocks. Various lines of evidence for and against
both magmatic and metasomatic origins for the Bauchi
rocks are examined; the equivocal nature of much of
this evidence is stressed.

The weight of petrographic and field evidence, backed by the plutonic setting and spatial distribution of the different rocks, is thought to indicate a metasomatic origin for the migmatites, the Biotite Granite and the Biotite Hornblende Granite. The Quartz Diorite and the Fayalite Quartz Monzonite are demonstrated to be related the Charnockite series; they originated by a soaking of the Biotite Granite and the Biotite Hornblende Granite respectively with dilute basic magma or solutions under deep seated conditions. It is suggested that the basic solution could have originated from the basic material displaced in the zones of granite and migmatites. The petrology of the Bauchi rocks is considered in the light of problems relating to granites and charnockites in general.

The account includes ten chemical analyses of rocks from the Bauchi area, as well as optical data on the minerals and numerous modal analyses.

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CHAPTER I.   INTRODUCTION.

Location and Topography.

Bauchi town, in the centre of the district under
study, is situated in the north-east of Nigeria.   It is
in the middle of one of the extensive outcrops of the
Older Granites which, with the Archaean Schists,
amphibolites, granulites and calcsilicates are, generally
termed the Undifferentiated Basement Complex in the
provisional map of Nigeria,   (Fig. 1).   The area studied
lies between longitude $9^0 45'$ and $9^0 55'$ East and
latitude $10^0 15'$ and $10^0 23'$ North,   immediately East
of the central plateau of Nigeria and the Younger
Granite ring-dyke complexes.

The district is generally about 2,000 feet above
sea level and according to Bain (1926) the general fall
of the country is to the East and South.   The country
appears as a flat plain broken only by inselbergs or
island hills, but this plain is actually a number of
low domes which is only truly appreciated as the crests
are reached and extensive views of the surrounding
countryside suddenly emerge (Frontispiece).

The inselbergs occur in seperated clustered
groups of various shapes among which whale backs,
turtle backs, and cones (much resembling volcanic cones)
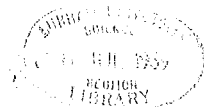
are the most common. (Plates 1 and 2.) Less commonly
the Older Granites form jagged chains of hills much
resembling the hills of the Younger Granites; the Buli
hills being the most prominent example of this (Plate 2
fig. B.)

All the hills, whether whale back, cone, or jagged
chain, tend to be elongated in a north-east south-west
direction, parallel to the general strike of the
foliation of the rocks. (Fig. 2)

Field work and nature of outcrops.

Two field investigations lasting eight and five
months respectively were carried out, both during the
dry season when the grasses were burnt laying bare the
surface and thus enabling the writer to study
practically all exposures. The outcrops are very
widely seperated and almost entirely limited to the
hills and their immediate surroundings. The degree of
exposure may be appreciated from the accompanying map
(A) on which the principal groups of outcrops are
indicated.

Mapping was done on aerial photographs, transferred
directly on to a preliminary map of the same scale and
subsequently on to a reduced copy of the same map. The
aerial photographs were supplied by the Survey

Department of the Northern Region of Nigeria who also
prepared and supplied the two maps.   The district has
many good roads and numerous foot paths (see Map A)
all clearly shown on the photographs.

History of Geological Investigation.

The Older Granites of Bauchi district were first
investigated by Falconer (1911) who described them
during the general economic survey of Northern Nigeria.
In 1926 Bain mapped and examined them in some detail.
Since that date the granites of this district have
not been examined, but some study of Older Granites
in other parts of Nigeria has been done, mostly as a
subordinate investigation of the Younger Granite
masses which they surround.   In 1949, the Osi area in
Ilorin province was studied by DeSwardt and King (1949),
and more recently, the Ilesha district by DeSwardt
(1953).   Even from this scanty information the great
similarity of most of the Older Granites extending
over nearly two-thirds, of the country, is very
striking.   Some of the descriptions of the Older
Granites by King and DeSwardt (1949) and DeSwardt
(1953) could be used word for word for certain of the
granites of the Bauchi district.

Geological Setting.

The gneisses, gneissose granties, granites, granodiorites, diorites and migmatites in this complex are collectively known as the Older Granites. This distinction appears to have been first made by Falconer (1911) to differentiate them from the Plateau Granite ring intrusions known as the Younger Granites. He believed that the Older Granites were collectively an ancient igneous complex. Stratigraphical age determination of both the Younger and the Older Granites is impossible and very little can be said beyond stating that the latter are older than the former. For no stated reason it is commonly believed th that the Older Granites are definitely PreCambrian and the Younger Granite either late PreCambrian or early Paleozoic (Macleod, personal communication).

Apart from the more obvious fact that the Younger Granites are ring-dyke intrusions and the Older Granites are of doubtful mode of emplacement, various distinctions have been made between the two classes. Raeburn (1926) suggested that the Younger Granites are, in contrast, soda-rich and this chemical difference was expanded by Mackay (1949):- "Chemically the older have less soda, somewhat less potash and

more lime than the younger". Genetically, the Older
Granite, unlike the Younger, is held to be more deep
seated and there is considerable doubt that they were
ever molten (Mackay, 1949). The Older Granites
generally show some foliation (Falconer, 1926) and are
less resistant to erosion, weathering to isolated groups
of inselbergen, whereas the Younger Granites form a
high dissected plateau with steep escarpments (Jacobson
and others, 1958).

The oldest member of the basement complex are
granulites, amphibolites and calcsilicate rocks. The
granulites, associated with subordinate calcsilicate
rocks, occur mostly as thin lensoid relics in the
gneisses, sometimes sharply demarcated and at other
times grading into them. Commonly they form irregular
elongated strips intercalated between quartz-feldspathic
bands thus forming lit-par-lit gneiss; irregular
patches showing microfolding are common but too far
apart to be correlated to form any intelligible picture.

The calcsilicate rocks in general appear as narrow
elongated bands in the ~~granite~~ granulite. Sometimes they can be
followed for a few yards, but in general are rather
short and discontinuous. Their contacts with the
surrounding granulite are sharp but comformable. North
of Miri, the largest calcsilicate body forms a wall-like

body about 18 inches wide, standing nearly three
feet above its surroundings and almost twenty-five
yards long.

The gneisses in which these rocks form patches
are of two types, feldspathised and unfeldspathised.
The latter was probably that designated "soft gneiss"
by Falconer (1911) and the former is termed "hard
gneiss". Falconer's statement that no boundary can
be definitely placed between these two was confirmed.
The "hard gneiss" has developed prominent microcline
porphyroblasts from 0.02 sq.cm. to 0.1 sq.cm. in
size and the "soft gneisses" form scattered patches
within it.

The "soft gneiss" is generally strongly lineated
and is more or less always deeply weathered (probably
why it is called "soft gneiss" by Falconer, since he
gave no reason for so designating it). The "hard
gneiss" is much fresher and in most cases it is nearly
free of gneissose banding being more homogeneous and
granitic. This led Bain (1926) to describe it as the
"feldspathic" granite. In the present work it is
called Biotite granite (Map A). The rock is
characterised by extremely variable distribution of
biotite and microcline, the former increasing locally
where granulite or amphibolite ghost relics (schlieren)

are common.

In some places the rock has been baked along narrow zones by underlying basic dykes becoming brick red in colour, more feldspathic and with decomposition of the biotite.

Quartzo-feldspathic dykes are common and often associated with veins. With increase in the veins and dykes, the rock gradually gives way all along a north-western front to agmatitic gneiss where the gneisses are dissected into angular blocks of various shapes. (Plate 3) Bain described this as brecciation (Bain 1926). In this agmatitic mixture the dyke rocks are as abundant as the gneisses. Several generations of the dykes and veins can be observed and the later ones may appear to displace the earlier ones slightly. They vary considerably in width from a few inches to two feet and in length from a few yards to several tens of yards. These dykes may be pegmatitic, coarsely granitic, or aplitic. When pegmatitic they usually show a zoning from a central line of pegmatite, laterally into granite. Generally they are never sharply demarcated from the gneisses, though the colour contrast gives the contrary impression. The enclosed blocks show no relative displacement as result of being so dissected by the

"metatectites" (the dykes and veins, Barth 1951,
p. 365) and the foliation in one block is concordant
with that of the surrounding blocks. (fig. 3) Large
microcline porphyroblasts no doubt of the material
of the metatectite are commonly present in these
blocks. (fig. 3).

Further north the agmatitic gneiss gradually
merges with mixed gneisses and pegmatite dykes. The
dykes strike approximately 280^0 and are concordant
with the general lineation of the gneisses. They
are chiefly composed of microcline with some quartz,
and may contain some muscovite. They vary in width
from one to three feet and may be zoned with muscovite
and quartz towards the centre and microcline on the
outside. Locally, there may be more pegmatite dykes
than gneisses.

The feldspathised gneiss, the agmatitic gneiss
and the mixed pegmatite dykes and gneisses are
collectively regarded as migmatites by the present
writer.

Surrounded by an aureole of Biotite Granite,
there are the rocks of the "Bauchi Batholith". They
consist of three principal members: The Fayalite-
Quartz Monzonite, the Biotite-Hornblende Granite and
the Charnokitic Quartz Diorites. Between these, local

variations occur which do not fall into this broad classification (Map B).

The Fayalite-Quartz Monzonite covers the whole of Bauchi town and extends north-westwards and eastwards into the Kwini and Dumi Hills respectively, an area of nearly twenty square miles. Another exposure covering Baskin Hill and extending southwards for nearly two miles is about two square miles in area. Smaller outcrops occur around Miri and a charnokitic phase appears around Yelwa bridge on Kwalanga river (Map A).

The rock has a somewhat crushed appearance around Bauchi town. Jointing is poorly developed and weathering is largely by exfoliation resulting in whale backs (Plate 1 fig. B), with individual boulders forming large cannon balls due to onion weathering. Lineation, so common a feature of rocks in this district, is weak or totally absent.

Inclusions are common. These are of a dense fine grained granitic rock (Plate 4, Fig. A.) which microscopic examination reveals to be a microcline granite with low mafic (biotite-hornblende) content.

The rock was called Porphyritic Older Granite, "syenitic type" by Bain (1926) and described as a pyroxene syentie - the fayalite being mistaken for "enstatite" and ferrohedehbergite for "magnesium

diopside" Bain 1926 p. 47).

In the north-east the rock grades into the Quartz-Diorite, patches of which are to be found inside it all along the east and south margins (Map B). The Quartz-Diorite is extremely variable in texture and sporadic occurrence of large microcline crystals is common. On the east side of Kwini Hill and on Inkil Hill considerable areas can be seen where these large microcline crystals are so abundant the rock approaches the Quartz Monzonite in appearance. From such areas the microcline usually diminishes rapidly in size and abundance and soon regain the appearance of the usual diorite (Fig. 4).

The Biotite-Hornblende Granite grades sharply into the Fayalite-Quartz Monzonite which it surrounds like a jacket. No common contact is known between the diorite and the Biotite Hornblende Granite; the two are usually seperated by the Fayalite-Quartz Monzonite. The Biotite-Hornblende Granite is strongly lineated striking about 220^0 except in the North West, where it turns east-west. Generally this lineation is concordant with that of the surrounding gneisses. As in the monzonite, fine grained granitic inclusion are common, principally of quartzo-feldspathic rocks with a scanty amount of biotite. At times the inclusions

may appear aplitic, and vary in size from a few square inches to several square feet.

Two other rock types occur in the district. One is a medium grained Biotite-Hornblende Granite which, covering half of Ran Hill and running transgressively southwards, fades out into the gneisses about two miles North of Bauchi. A smaller narrow outcrop near Kundum village strikes east west. The other is a medium grained Biotite Granite and occurs like a roof pendant situated between the diorite and the fayalite quartz monzonite.

Structual Features.

The Fayalite-Quartz Monzonite with the diorite and the Hornblende-Biotite Granite to which it grades form a body of batholithic dimensions. Together they make up an extensive mass with a known surface area of about 80 square miles, while about another 80 square miles may be inferred from the map between Bauchi town and Miri Village. Their southward extent is not known but eastward they appear to continue to Kangeri (Fig. 5). They are of undeterminable depth and deep seared, and show many other batholithic characters such as variable colour and composition, porphyritic

texture, and indefinite boundary. This complex could thus be called the "Bauchi Batholith."

No major fault is directly observed, but some may be inferred from possible breccias and from the aerial photographs, (Plate 4, fig. B), these are shown on Map (B). Small fault displacements are frequently found in the migmatites. They are usually short, often less than a yard long with a displacement of from two to eighteen inches. The faults strike in three directions; $10-20^{\circ}$, $340-350^{\circ}$ and $310-320^{\circ}$.

Several zones of cataclastic deformation are marked by augen gneisses. They are indicated on Map (B)

Jointing is not prominent in the Bauchi Batholith but rather common in the migmatite, (Plate 5, fig. A), the different sets are represented diagramatically in fig. 6.

The general foliation is north east - south west, but local variations occur, and it is generally concordant with the foliation in the schists and granulites. Shading in Map B shows this foliation, as reconstructed by the writer from information shown on Map A (arrows).

Contact Relationship

Contacts between the rocks of this district are

of very indefinite character and poorly exposed. The contacts between the different gneisses and also between the Biotite Granite and the Biotite Gneiss are unquestionably gradational. The nature of the contact between the Biotite Granite and the Biotite-Hornblende Granite is rather more varied: East of the Zungar hills and east of Miri, outcrops showing gradation from one to the other can be seen, but south of the Agricultural Department farm and just east of the Yelwa Bridge a definite line of contact is seen, but this is actually a line of textural contrast.

The contacts between the different members of the Bauchi batholith are gradational. Gradation from the Biotite-Hornblende Granite to the Fayalite-Quartz Monzonite is rapid but can be seen in the Dumi hills just north of the village. The contact between the Quartz Diorite and the Fayalite-Quartz Monzonite is for a large part obscured by Medium-grained Biotite Granite which sits like a roof pendant over both, but in those places where the diorite is within the monzonite, the contact can be seen to be gradational.

The contacts of the medium grained Biotite Granite are sharp all round but unchilled (Plate 5, fig B)

In the Ran hills, the medium grained Biotite-Hornblende
Granite has similar contacts with the Biotite Gneiss
but towards its southern end, in the neighbourhood
of Meriamma Hill, it changes character and the rock
merges with the surrounding gneisses.

The Charnockitic Diorite where it occurs within
the gneiss, as in the west part of the area around
the Jos road, from the closeness of outcrops belonging
to the different rocks, appears to have a sharp contact.
Here again the contact may be no more than a line of
colour contrast.

Dykes.

In the north-west of the area a number of soda-
trachyte dykes cut through the migmatite, but none was
found in the rocks of the Bauchi Batholith. These
dykes are approximately vertical with good rectangular
jointing. They are usually two to five feet wide and
can in some cases be traced for a mile or more (Plate 6
fig. A).

Dolerite dykes, usually about 18 inches broad, are
themost widespread. They cut across all the rocks in
the district and strike rather consistently in an east
west direction. The larger dykes may carry numerous

blocks of the country rocks;   the inclusions are
altered both texturally and mineralogically.   Three
such dykes are known and are marked on the accompanying
maps. (A and B).

Few granitic dykes are observed.   (All the dykes
are indicated on map A.)

Sequence of Geological Events.

The earliest rocks, now represented by the
amphibolite, granulites and calcsilicate rocks, are
believed to be sedimentary in origin and were once
widespread (Bain 1926, Falconer 1911).   Assuming
these to be the ancient sediments, the sequence of
geological events leading to the present exposed rocks
are summarised in Table 1.   The sequence as interpreted
by Bain (1926) who regarded all the rocks as intrusive
is shown in Table 2, constructed by the present writer
from information given by Bain (1926, p. 61-63).

TABLE 1

Ancient Sediments			Sedimentation
Schist cycle.	1. Schists 2. Quartzite 3. Meta-lime-stone lenses.	Folding and faulting of the sedi-ments.	Progressive Metamorphism
Basic Dykes			
Migma-tite cycle	4. Gneisses 5. Pegmatite dykes 6. Quartz-feldspar veins. 7. Relict rocks: granulites amphibolites (from basic dykes) calcsilicates (from meta lime-stone) 8. Migmatites	Period of injection and wide-spread diffusion of Si and K. Faulting on a small scale	Migmatization microcliniza-tion.
Basic Dykes			
Granite Cycle.	9. The biotite-hornblende granite. 10. Fayalite quartz-monzonite. 11. Quartz-Diorite	Period of increasing diffusion of Si, K, Na, Mg, Fe and Ca.	Intense micro-clinization and recrystallization
	12. Massive quartz-reefs.	Period of alteration	Silification Epidotisation
Soda Trachyte Dykes, Dolerite Dykes, Granitic Dykes			

Weathering since Precambrian forming Inselbergs and low-lying domed plains.

For the same district the sequence as visualised by Bain is shown on Table 2 drawn from information given by him. (Bain 1926) He regarded all the rock as definitely intrusive.

TABLE 2

	Ancient Sediments	
Schist cycle	1. Calcic rocks (Calc-silicate rocks). 2. Biotite Schists. 3. Biotite garnet schist (granulites)	Recrystallization from dynamic and to a less extent thermal metamorphism.
Granite cycle (Migmatite cycle.)	4. Primary banded gneiss (lit-par-lit gneiss). 5. Biotitic granite (βiotite gneiss).	Injection of quartz feldspar veins. Intrusion of acid rocks. Injection of massive pegmatites with tourmaline and brecciation of older rocks.
	Period of Quiescence (no evidence given)	
Porphyritic Granite cycle. (Granite cycle).	6. Fine Grained feldspathic granite (feldspathise gneiss; biotite granite). 7. Porphyritic Older Granites with syenitic types (Biotite Hornblende Granite, Fayalite-Quartz Monzonite)	Intrusive activity.
	7a. Syenitic dykes. 8. Granitic and Trachyte dykes. 9. Basic dykes.	Dyke intrusions.

The above table is from information given by Bain (1926 p. 61-63) The lithological classification from Table 1 are shown in brackets against Bain's.

CHAPTER II   THE DESCRIPTION OF THE BAUCHI ROCKS.

Classification

The rocks of Bauchi can be classified as shown in table 3.   They are arranged in order of probable age, with the oldest at the bottom.   (Note: dykes are excluded)

TABLE 3.

7.   Quartz Diorite (charnockitic) (Youngest?)

6.   Fayalite-Quartz Monzonite (variable within quartz
                              syenite and adamellite)

5.   Biotite-Hornblende Granite.

4.   Medium Grained Biotite Granite.

3.   Medium Grained Biotite-Hornblende Granite

2.   Migmatites: a.   Biotite Granite.
                     b.   Biotite gneiss.
                     c.   Mixed gneiss and pegmatites.
                     d.   Agmatitic gneiss.
                     e.   Lit-par-lit gneiss.

1.   Metasediments:

                     a.   Arkosic Quartzite.
                     b.   Calcsilicate Rocks.
                     c.   Amphibolite.
                     d.   Hornfelsic granulite.
                     e.   Granulite. (Oldest)

Description of Metasediments

The Granulite has a salt and pepper greyish colour with reddish spots of disseminated garnet.   Pegmatitic

knots are common, usually surrounded by a feldspathic halo.

Under the microscope the rock is seen to have a lepidoblastic texture (Plate 7 fig A) and is composed largely of plagioclase, biotite and quartz (Table 4). The biotite is pale brownish green in colour, and the plagioclase is oligoclase. The latter has a crushed appearance and generally shows very poor twinning. The quartz has very strongly undulatory extinction. Garnet porphyroblasts occur in scattered ragged grains with inclusion of, and intergrowth with, quartz vermicules and blebs. The outline of the garnet is amoeboid, and it embays adjacent minerals appearing to be preferentially replacing plagioclase and biotite. It is identified as almandite.

The Hornfelsic Granulite appears to be a granulitic relic which has been locally baked (ME179). Only two small patches are known in the area and these occur in the south-east of Bauchi town and just south of the air strip (Map A). The rock has acquired a purplish hue from the red colour of the biotite and the garnet, and has developed quartzo-feldspathic veins.

Under the microscope the rock is seen to be hornfelsic in texture and to have been recrystallized.

The plagioclase and the quartz show far less marked crush effects. The biotite is reddish in colour. The quartzo-feldspathic veins are seen to be lensoid in shape and composed of coarse aggregates of oligoclase, potash feldspar and biotite. Small areas of myrmekite may occur at the border between plagioclase and potash feldspar (Plate 7 fig. B).

The only occurrence of amphibolite is that about half a mile north of Bauchi town and just inside the road fork. Here the amphibolite has been dissected into blocks and partly digested (Plate 8 fig. A). The rock is dense and black in colour in the central portion of the blocks but towards the borders against the encasing granite it becomes coarsely biotitic.

As seen under the microscope, the rock is granoblastic (Plate 8, fig. B) and composed mainly of hornblende, plagioclase and biotite (Table 4). The hornblende is strongly pleochroic from pale yellowish green to deep bluish green. The biotite is yellowish brown in colour and pleochroic to dark brown.

The plagioclase is of the composition of oligoclase (An80 Ab20) and may show zoning. The biotite zone near the border with granite is seen to be a

coarsely recrystallized aggregate of biotite, oligo-
clase and quartz. It contains more quartz than the
amphibolite core and some calcite and sphene appear as
accessory minerals.

The Arkosic Quartzite is the least common of the
Archaean metasediments and only one exposure, near the
air strip (Map A) is known and this is so limited that
the structureof the rock cannot be determined. It is,
in hand specimen, a grey massive rock with disseminated
pyrrhotite.

Under the microscope, the rock has a granoblastic
texture (Plate 9, fig. A) and it is composed of
microcline (41%), plagioclase (34%) and quartz (25%).
Opaque ore, presumably manganous oxide, occur as
patchy clots and as an intergranular stains (Plate 9,
fig. B).

The Calcsilicate Rocks are usually dense and
almost flinty. Commonly, they are banded in tints of
green and red, corresponding with alternative zones of
pyroxene and garnet, or less frequently in green and
white, corresponding to the zones of pyroxene and
quartz and feldspar. Massive calcsilicate which is
not banded is mottled greenish and reddish due to
patchy concentrations of pyroxene and garnet.

The mineralogical assemblages are shown in Table 4.

The pyroxene occurs in large equant grains or in large poikiloblastic masses (Plate 10, fig. A) It is identified (Table 7) as a ferrosalite with $MgSiO_3$ 26%, $FeSiO_3$ 43% and $CaSiO_3$ 31% corresponding to about 1:1 proportion of diopside and hedenbergite. (Hess 1949)

Scapolite is abundant especially when the plagioclase is not appreciable and presumably has occurred in place of it under some special conditions not fully known (Fyfe 1958 p. 160). The plagioclase is a bytownite (about $An_8 Ab_2$). In some specimens (ME 237) it may have a checkerboard structure, containing small cubes of what appears to be a plagioclase of lower refractive indices. The parallel extinction of these cubes suggests Oligoclase ($Ab_{75} An_{25}$). Many of the crystals show weak zoning. The garnet has a refractive index which varies between 1.752 and 1.768, and it is believed to be grossularite. It occurs in equant grains or irregular poikiloblastic masses which may contain any of groups of the other minerals (Plate 10, fig. B). Quartz and calcite are commonly present in varying proportions and the twominerals may occur contiguously with no reaction zone. For

some reason calcite tend to occur mostly in or
associated with grossularite.

Sphene is the titaniferous phase in all specimens
andoccurs commonly as disseminated grains and,
occasionaly, as clotted granular aggregates.

Description of The Migmatites

The Migmatitic rocks of Bauchi had been variously
described as gneisses, gneissose grantie, lit-par-lit
gneiss and igneous breccia by Bain (1926). The present
classification is shown in Table 3.

The lit-par-lit gneiss consists of alternating
parallel bands of granulite and granitic rocks with
some intercalated quartz veins (Fig. &). The granulite
bands as well as the granitic bands vary in width
from fraction of an inch to several inches. Narrow
elongated bodies of calcsilicate rocks may be found
associated with the granulite. As seen over a wide
area, the structure is one of parallel banding, but on
close examination, the granulitic bands may exhibit
varying degrees of folding.

The granulite component of this gneiss has been
previously described. The granitic portion is
composed mostly of quartz and microcline. The texture
is often irregular due to sporadic development of

TABLE 4

MODAL ANALYSES OF THE METASEDIMENTS

	1	2	3	4	5	6	7	8	9	10
K. Feldspar	–	1	–	–	–	–	–	–	–	–
Plagioclase	38	38	36	5	36	31	28	42	32	2
Pyroxene	–	–	–	31	17	38	21	40	30	15
Hornblende	–	–	35	–	–	–	–	–	–	–
Biotite	36	37	25	–	–	–	–	–	–	–
Garnet	5	6	–	15	33	–	40	–	19	45
Quartz	21	18	2	20	13	25	8	10	11	10
Scapolite	–	–	–	20	–	–	2	1	7	13
Calcite	–	–	–	–	–	–	–	–	–	15
Sphene	–	–	–	4	1	6	1	6	1	Tr.
Epidote	–	–	–	15	–	–	–	–	–	–
Ore	–	–	2	–	–	–	–	1	–	–
	100	100	100	100	100	100	100	100	100	100

1. ME. 220   Granulite inclusion in Migmatite, Ran Hill.

2. ME. 179   Hornfelsic granulite, S. E. Bauchi Town.

3. ME. 206A. Amphibolite, $\frac{1}{2}$ mile north of Bauchi Ran Gate.

4. ME. 171   Calcsilicate rock, Tara Hill.

5. ME. 173   "   "   , $\frac{1}{2}$ mile south of
                                    Kundun Village.

6. ME. 170   "   "   "   "   "

7. ME. 172   "   "   East of Sanfara Village.

8. ME. 237   "   "   Ran Hill.

9. ME. 240   "   "   "   "

10. ME. 165   "   "   1 mile north of Miri.

of pegmatitic phases. A thin band only an inch or less wide may sometimes be traced for nearly a hundred yards and the quartz veins and stringers which are very widespread can be equally persistent over a length quite out of proportion with their breadth.

Th agmatite gneiss has two components also, the angular blocks of gneiss and the dissecting granitic dykes. (see Plate 3) The gneissic blocks vary widely in their appearance. Generally they are grey in colour and show foliation which is best appreciated in the field, especially on wet or old surfaces. This foliation is consistent from one block to the other. Large, sparsely distributed microcline porphyroblast about 3 sq. cm. across are frequently present.

Under the microscope the rock is granoblastic and is composed principally of oligoclase, quartz and biotite, (Plate II fig A), and microcline porphyroblast may be present. The oligoclase is about $An_{80} Ab_{20}$ average composition. It is generally very poorly twinned. The quartz is in irregular larger masses and most grains show strong undulatory extinction. The biotite is greenish brown and pleochroic from brown to dark brown. It is more or less arranged along parallel zones and, as seen under

the microscope, appears to be the only mineral affecting the foliation structure as observed in hand specimen.

The microcline porphyroblasts, (Plate 11, fig B.) show strong gridiron as well as simple Carlsbad twinning, microperthitic structure is absent but inclusions of quartz, feldspar and biotite, which are presumably relics, are fairly abundant, especially round the margins. Though oblong shaped and rather subhedral looking, its margins can be seen to be sutured with those of the surrounding minerals. Smaller grains of microcline and ragged pieces of muscovite occur in the immediate vicinity of the porphyroblasts though absent in the main portion of the rock.

The metatectite is composed largely of microcline, quartz and a subordinate quantity of plagioclase. Rarely garnet crystals (almandite) may be found and muscovite is not uncommon, especially in the more pegmatitic dykes. The microcline is commonly microperthitic and clear while the plagioclase is often clouded with alteration. Quartz has strong undulatory extinction. When present muscovite occurs in plates with ragged edges.

The contact between the metatectite and the

gneissic block is gradational though the strong colour contrast gives a contrary impression, especially when viewed from a distance. When closely examined (ME. 259, plate 12 fig A) there is mutual interpenetration of the metatectite and the gneiss components.

The Mixed Gneiss and pegmatites differ from the agmatite gneiss in that, in the former the dykes have a consistent strike direction, about 280° and are in general concordant with the foliation of the gneisses. Locally a small area may be wholly of pegmatite developed from the union of many dykes.

The gneiss is the same as that described for the agmatite gneiss. The pegmatite often show zonal distribution of its mineral components. Quartz frequently occurs along a central line surrounded outwards by large microcline crystals. Not uncommonly quartz may be completely absent, or nearly so, the dyke consisting almost wholly of microcline. Occasionally muscovite may be oresent, it is localised in the central zone with quartz. In rare instances large crystals of almandite garnet occur. In one locality, a dyke was found consisting entirely of interlocking crystals of quartz and muscovite (MEF 117).

The microcline crystals average about 10 cm. square

some crystals may be two or three times larger
(Plate 12, fig B).   They are generally flesh pink
but white crystals are sometimes observed under the
microscope,   the feldspar is perthitic containing vein
type blebs of plagioclase which form a high proportion
of the crystal.   The blebs have parallel extinction
and are believed to be oligoclase.   The microcline
shows strong gridiron twinning.   Few and small
inclusions of quartz may be present.

In handspecimen the quartz is crystal white and
massive and the muscovite is colourless but usually
stained by dirt and limonite.   The muscovite is
rarely more than 7 cm. long and 4 cm. wide.   A book
of muscovite is rarely more than 2 cm. thick.

Pegmatite is found widely distributed in the
migmatitic rocks though in much less concentration
outside this area.   In the neighbourhood of Guru,
black tourmaline may be associated and some crystals
are up to 7 cm. long and 4 sq. cm. in cross section
(Plate 13, fig. A).   Rarely they are found taking the
place of feldspar in a graphic pegmatite (Plate 13,
fig. B).

The biotite gneisses are very variable both in
the proportion of biotite and in degree of foliation.

Frequently the foliation is strong and the rock shows

bending (ME. 185, Plate 14 fig. A). The darker band

consists of thin parallel strings of alternating

biotitic [quartzo-feldspathic aggregates. The light
      and

bands are dominantly aggregates of quartz and feldspar.

The different bands are not as regular as the

illustration may suggest, being inconsistent in width

and rather discontinuous. Occasionally the banding

is vague (ME. 188 Plate14, fig. B) and the light and

dark areas are irregularly distributed. The gneissose

structure in such can readily be appreciated only over

large exposures and on an old surface.

Under the microscope the first type is seen to

be of xenomorphic granular texture and composed of

plagioclase, microcline, biotite, quartz. (Plate 15,

fig. A) The plagioclase is an oligoclase, often

clouded and altered. The microcline generally shows

strong gridiron twinning but a few perthitic

untwinned crystals may be observed. The microcline

is intergranular and sutured with the surrounding

minerals. Quartz occurs in large masses and elongated

bodies, and is weakly undulatory extinction. Small

blebs and vermicules of quartz occur over most of

the plagioclases imparting a corrosion appearance to

the rock as a whole. Some myrmekite is present.
Biotite plates are arranged along parallel lines and
some muscovite is present as ragged plates. In the
case where the banding is vague, the rock is composed
of plagioclase, biotite and quartz which appears to be
much recrystallised. (Plate 15, fig. B) Patchy
areas, free of biotite, are observed to have inter-
granular microcline.

These two rocks are evidently quite different
from each other in texture and modal composition,
however they are not unrelated but are two extreme
local variations within the same group.

The Biotite Granite is, texturally, the most
granitic of the migmatites. The rock is less
conspicuously foliated, but on wet or fairly old
weathered faces a foliation can be discerned.
Schlieren or ghost relic are abundant and pegmatitic
knots are common. The rock, like most of the other
migmatitic rock is widely variable in colour, grain
size and modal composition; even in the hand soecimen
this variation may be appreciated. Its chief unifying
characteristic is the presence of a large number of
small porphyroblasts about $\frac{1}{2}$ sq. cm. (Plate 16, fig. A).
Occasionally the porphyroblasts may become numerous

and larger, attaining 3 sq. cm. in size (Plate 16, fig. B). Then, the groundmass becomes coarser and the resulting rock is hardly distinguishable from the biotite hornblende granite of the Bauchi batholith. Garnet (almandite) may occur as segregated bodies surrounded by quartzo-feldspathic zones free of biotite. (The principal field characters of this rock are summarised in Fig. 8.)

Under the microscope, the rock has a granoblastic texture and is composed of microcline, oligoclase, quartz and biotite (Plate 17, fig. A). The larger microcline porphyroblasts are nearly always poikiloblastic enclosing relic minerals from the groundmass. Gridiron twinning is pronounced and there is some tendency to develop microperthitic texture and myrmekitic fringes. Generally the outline of the porphyroblast is lost in sutured interlobing with the fringing minerals and the development of myrmekite.

The plagioclase is oligoclase (Ab_{80} An_{20}) and is clouded to variable degrees. Quartz occur principally in large irregular masses, and may show strain effects, but quartz vermicules and blebs associated with myrmekitic activity are also abundant.

Biotite is on the average very scanty. Commonly, there may be slight alteration to chlorite and over-growths of muscovite may sometimes be observed.

The medium grained Biotite granite

The rock is similar to the Biotite granite in most of its features except that it has slightly larger and more closely spaced porphyroblasts. Further it has a darker greyish colour.

Under the microscope, the rock is composed principally of plagioclase, potash feldspar, biotite and quartz, and the texture is granoblastic (Plate 17, fig. B). The plagioclase is in plates of various sizes, many of which show strain by their bent lamellae and wavy extinction, some are clouded with alteration and a few show weak zoning. The average composition is about Ab_{25} An_{75}. The microcline porphyroblasts contain small quartz inclusions and are surrounded by small areas of myrmekite. Biotite is abundant, and arranged along clustered branching lines surrounding the feldspars. It is a brown biotite and may be partly altered to chlorite. Quartz occur in large masses showing varying degrees of strain extinction.

Medium Grained Biotite Hornblende Granite.

The rock is extremely variable. In colour many
shades of grey and reddish grey are present; in
texture, it is generally about fine to medium grained
with microcline porphyroblasts varying from abundant
to practically absent and from 2 sq. cm. to $\frac{1}{2}$ sq. cm.
in size. In the occurrence to the south of Bauchi
very large porphyroblasts about 4 sq. cm. may occur
sproadically.

Under the microscope the rock is of granoblastic
texture, (Plate 18) and is composed of microcline,
plagioclase, biotite, hornblende, quartz, orthite
and ore.

The microcline is of two types, one which occurs
as small irregular grains in the ground mass, with
strong gridiron twinning and no myrmekite or perthite
associated with it, and the other, which occurs as
porphyroblasts in large irregular grains with poorly
developed gridiron twinning but good film and patch
perthitic structures. Inclusions of quartz, biotite,
hornblende may be present and myrmekite is commonly
developed around the fringes.

The plagioclase, an oligoclase, has zero to
slight extinction. It may show slight strain and is

generally clouded with alterations products. Biotite and hornblende occur in irregular plates with the former generally more abundant and the latter rather variable, sometimes nearly absent. The hornblende is generally as overgrowths on the biotite.

Quartz is common and may show very strong strain extinction.

Orthite and opaque iron ore are other accessory minerals, the former in irregularly coloured brown plates.

Description of the rocks of the Bauchi Batholith.

The outer zone of the Bauchi Batholith is composed of a very coarse granite with large microcline crystals averaging about 4 cm. by 1. 5 cm. and set in a coarse matrix of quartz, feldspars and ferromagnesian minerals. These microcline crystals are arranged more or less parallel imparting a slight lineation to the rock. (Plate 19) Locally the rock may appear crushed, becoming strongly gneissoid, and the microcline crystals crowded and elongated. The distribution, size and colour of the microcline is also variable in this rock. This feldspar is generally light coloured, white, pinkish or yellowish brown. The quartz is

TABLE 5

MODAL COMPOSITION OF THE MIGMATITIC ROCKS.

	1	2	3	4	5	6
Microcline Perthite	39	8	23	28.3	23.4	21.1
Plagioclase	23	56	37	27.3	32.1	33.4
	31	17	20	22.3	22.5	21.6
	5	19	17	11.0	13.4	18.7
	--	--	--	7.0	6.3	1.5
	2	Trace	2	1.1	1.0	2.5
	--	--	Trace	1.0	0.9	1.2
	--	--	--	0.6	0.9	Trace
	--	--	--	0.2	Trace	Trace
	--	--	--	0.3	Trace	0.2
	0	100.0	99.0	99.1	100.5	100.2

Gneiss West of Kasuma Hill.

" Foot of Shadawanke Hill.

ained Biotite Granite,
North of Wombai Hills.

ained Biotite Hornblende Gramite,
Ran Hill.

5. ME. 212 Same as above about 1 mile south of
Ran Hill.

6. ME. 176 " " " Near Gundun Hill.

invariably colourless.

Under the microscope the rock is composed of microcline microperthite, plagioclase, quartz, biotite and hornblende, and it is of allotriomorphic granular texture (Plate 20, fig. A).

The microcline is crystaloblastic: it has amoeboid outlines, interlobing with the surrounding minerals. It is microperthitic, the plagioclase blebs are of stringlet type (Alling 1932) and barely resolved under the low power (X5) objective. In the larger blebs, string and film types of perthite are occasionally observed. The microcline crystals are phenocrystalike being generally much bigger than the other minerals present. They may be fringed by a chain of myrmekite or a garland of a fine mosaic of quartz and feldspar. Inclusions are commonly present but are not abundant. Gridiron twinning is weak to absent. The optic axial angle is negative and generally very large ($2V=84^{\circ}$), corresponding to a high soda content or maximum lattice structure order. (Laves, 1952)

The plagioclase is oligoclase ($Ab_{80} An_{20}$). It occurs in large to small plates and generally show some strain effects, most evident of which is the bent twin lamellae. Weak zoning may be noticed in

some grains. Along the contact with plagioclase,
when myrmekite is not developed, a narrow selvedge
of reversed orientation of the twin lamellae may be
observed, (ME 233, Plate 20, fig. B).

Quartz occur in large masses. Some show undulatory
extinction while others have rather even straight
extinction. Vermicules and blebs of quartz occur in
myrmekite and as inclusions in the feldspars.

The ferromagnesian minerals are biotite and
hornblende. They are of very variable distribution
and proportion. The biotite occurs in clusters of
flaky plates and may be ragged. Rarely it occurs in
large irregular mass that is optically continuous
and pleochroic from pale brown to dark brown. Horn-
blende is commonly associated with the biotite. It
is a greenish brown in colour, and Pleochroic X =
greenish brown, Y = brownish green, Z = bottle green.
From the refractive indices (Table 7), it is identified
as an hastingsite.

Other less common accessory minerals are orthite,
which are euhedral to subhedral and strongly pleo-
chroic brown to deep brown, and iron ore which is
commonly associated with biotite though rather rare.
Zircon and apatite may be present.

The gradation to fayalite-quartz monzonite is rapid but it is marked by increased abundance of hornblende and to a lesser extent by the sporadic occurence of fayalite.

The Fayalite-Qaurtz Monzonite is the most distinctive of the rocks of Bauchi. It is massive and very coarse, the dominating large microcline crystals averaging 3 cm. by 2 cm. (Plate 21). It is characteristically brownish green with a peculiar resinous lustre. The large microcline crystals are unevenly set in a subordinate matrix of ferromagnesian minerals, quartz and plagioclase.

On oxidised surfaces the rock is dark brown, this is often seen and is what led Bain (1926) to describe them as "dark brown". However, at blasting sites the rock is found to be greenish on fresh surface. A fresh greenish specimen heated strongly for an hour turned to a dark brown colour similar to the oxidised surface in field, an indication that iron impregnation may be responsible for the colour.

The rock is of xenomorphic granular texture, (Plate 22, fig. A) characterised by mutual inter-lobing of the aggregate minerals. It is composed of microcline, plagioclase, quartz, fayalite,

orthopyroxene, hornblende with apatite, zircon and magnetite.

The microcline is microperthitic and the grid twinning is very poor. The microperthite is commonly of stringlet type, just barely resolved by the low powered (X5) objective and giving the crystals a velvety texture. The individual microcline crystal appears to be subhedral to euhedral in hand specimens, but on stained surface and under the microscope they are crystalloblastic, amoeboid in outline, and characterised by lobes and tongues with which they tend to embay other minerals. (Plate 12, fig. B) It may also be sutured by fine mosaic aggregates of quartz and feldspar. Inclusions of quartz blebs, and rounded plagioclases with reaction selvedges of incipient myrmekite are invariably present though not abundant. The 2V is 69° optically negative, smaller than those observed for the microcline in the migmatites and in the Biotite Hornblende Granite and suggesting lower soda content or a lattice structure of lower order.

The plagioclase is oligoclase-andesine (average, $Ab_{65} An_{35}$) It occurs in various sizes and irregular shapes; some are crystalloblastic. Bent crystals

and grains with crush fractures are commonly found
(Plate 23), though many crystals show no strain at
all. Small equant grains of feldspar may form a band
of mosaic aggregate between microcline crystals, and
skeletal bodies of optically continuous plagioclase
may occur in microcline towards the margin, forming
a type of patch perthite similar to those found in
the Quartz-Diorite.

Quartz is typically of resinous greenish brown
colour in hand specimen and variably distributed.
Under the microscope it occurs in large masses, some
showing strain undulatory extinction while others are
only weakly or not at all so. Quartz also occur in
myrmekite as vermicles and as small blebs included in
other minerals.

Fayalite is the distinguishing ferromagnesian
mineral. The composition is about 95% Fe_2SiO_4. (The
optical data are shown in Table 7). It is rarely
found as discreet grains but most commonly in
clustered aggregates with other ferromagnesian minerals.
These clustered aggregate of ferromagnesian minerals
are almost always associated with vein-like bodies of
quartz and arranged in the following generalised
pattern (Fig. 9); Iron oxide, if present occurs

along the centre in the quartz, the fayalite crystals then occur as discreet grains arranged round it followed outwards by crystals of pyroxenes, hornblende and plagioclase (Plate 24); but the pyroxene is not always present. The individual minerals occur as detached crystals which appear to be primarily crystallised and not as reaction mantles, except hornblende which may form an outer sheaf round the whole structure, and even these do not appear to be reaction mantle product on either the fayalite or the pyroxene, and may be seperated from them partly by a zone of quartz. They appear to have formed by reaction on the surrounding plagioclase.

Commonly fayalite may occur in a long-rod like body of optically discontinuous grains, wedged in between the large feldspar crystals (Plate 25, fig. A) but such bodies will be seen to be connected to a larger mass associated with other ferromagnesian minerals arranged as described above.

The clinopyroxene is commonly pale greenish with no appreciable pleochroism. It is indentified as ferrohedenbergite (Table 7). Inclusions of parallel needles of magnetite may occur in some grains to

form schiller structure. The mineral has rather irregular distribution and it may be absent from some sections, probably because of the coarseness of the rock.

Orthopyroxene is sometimes present and in some sections amounts to a considerable part of the ferro-magnesian minerals. It may be found interlocked with the fayalite.

Hornblende is the most abundant of the ferro-magnesian minerals. It may be found discreet but is usually associated with fayalite, surrounding the latter like a mantle as previously described. It is identified as ferro-hastingsite. (Table 7). It is greenish brown and strongly pleochroic as for that described earlier. Magnetite is the common inclusion. Biotite may be associated but is rather uncommon in this rock except near the transition zone towards the biotite hornblende granite.

A charnockitic phase of this rock occur around Yelwa bridge, on North band of river Gwalanga south-east of the aerodrome and near the Ran Gate, forming patches in the Marginal zones. This rock, (Plate 25, fig. B) is essentially like the fayalite quartz monzonite in hand specimen but tends to be richer in

in ferromagnesian minerals. Under the microscope
fayalite is absent and the mafic mineral assemblage
fayalite-hedenbergite-hornblende is replaced by
orthopyroxene-hornblende-biotite. The orthopyroxene
is identified as eulite about, $MgSiO_3$ 20% and $FeSiO_3$
80% in composition. (Table 7, Wahlstrom 1955 p.160).
It is strongly pleochroic X = brownish pink to
Z = green and presumably contains appreciable
$TiSiO_3$. It may occur in large masses that are
optically continuous or in elongated plates. Generally
there is a tendency to be localised in linear zones
and associated with hornblende (Plate 26, fig. A).
Inclusions of clino-pyroxene are sometimes observed.

The hornblende is very abundant and may occur in
large masses but usually ragged with associated
pyroxene. It is a deep green amphibole. It is also
a ferro-hastingsite.

The biotite is abundant and occurs mostly as
ragged plates or masses associated with hornblende.
It is a brown biotite with inclusions of apatite.

The plagioclase is andesine and slightly less
clalcic than that in the fayalite quartz monzonite,
(about $Ab_{67}An_{33}$).

The Quartz Diorite, to which the quartz monzonite

appears to grade, is a dark blue-black fine grained rock in the fresh hand specimen. It may be of uniform texture but quite commonly poorly defined area of what appears to be a larger crystal of microcline may be seen (Plate 27, fig. A). Stained surfaces show that these areas are of potash and plagioclase feldspars (Plate 27, fig. B). Occasionally, they become larger, numerous and better outlined. The rock is then hardly distinguishable from the Fayalite-Hornblende Granite to which it grades. Some specimens show lineation of these "ghost" microcline crystals.

Under the microscope the rock is seen to be of granoblastic granular texture (Plate 28, fig. A) and to be composed of plagioclase, potash feldspar, micro-perthite, ortho-and clino-pyroxenes, hornblende and some quartz with occasional biotite and rare fayalite. The plagioclase is andesine ($Ab_{60}An_{40}$). Zoned crystals are common and these often have an irregular calcic core or cores (Plate 28, fig. B). In one case the outer zone gives $2V = 87^{\circ}$ and the inner zone $2V = 76^{\circ}$; optically negative. Deformed crystals are not common but some crystals may show distinct bending of the lamellae (Plate 29, fig. A). The plagioclase in some specimens is characterised

by parallel inclusions of numerous needles of iron oxide (Plate 29, fig. B), but generally they are clear of alterations and sharply twinned on the albite law.

The potash feldspar is invariably microperthitic. The perthite blebs are extremely fine and just barely discerned under the low powered objective (X5) Commonly, irregular patches of optically continuous plagioclase may be observed enclosed within it, and these patches may be found to be optically continuous with a larger plate of plagioclase outside at the border of the potash feldspar (Plate 30, figs, A and B).

The ortho pyroxene is the most common ferro-magnesian mineral. It is strongly pleochroic; X = pale reddish pink, Y = reddish green, Z = green. It is identified as ferrohypersthene ((Ti) $FeSiO_3$, 75%; $MgSiO_3$, 25% (Wahlstrom 1955, p. 160))

The clinopyroxene is green with no appreciable pleochroism, and it is identified as ferroaugite ($CaSiO_3$ 40%, $FeSiO_3$ 39% and $MgSiO_3$ 21%, (Hess 1949)) The two pyroxenes always occur together associated with magnetite and amphibole, the former in clots and latter in shreds. Either magnetite or the amphibole may occur in minute needles arranged in

parallel zones forming schiller structure (Plate 31, figs. A and B).

The hornblende is ferrohastingsite. It occurs in ragged masses invariably associated with a core of pyroxenes. Biotite is rare in most specimens but locally abundant biotite may occur, associated with the other ferromagnesian minerals.

Some quartz occurs interstitially and rarely myrmekite is developed at the margin of microcline.

Magnetite is usually abundant and associated with the dark minerals.

Chemical Composition of Bauchi Rocks.

The Bauchi rocks are intermediate to acid in composition (Table 6) and only the Quartz Diorite shows normative olivine. Generally they show fairly high potash, average alumina and low magnesia content; and the ferrous iron ratio relative to the total iron plus magnesia, is very high.

The composition of the rocks plotted on Harker diagram (Fig 9) shows some peculiarities: The Alumina shows peculiar fluctuation but the values used are not sufficiently reliable to be regarded as conclusive. The potash has a peak in the Biotite Hornblende

TABLE 6

Chemical Compositions and Norms of Rocks from Bauchi District

	1	2	3	4	5	6	7	8
SiO_2	73.0	71.2	68.4	69.5	66.1	70.1	70.0	52.6
Al_2O_3	13.0	12.8	13.0	12.2	12.5	13.4	13.70	11.7
Fe_2O_3	0.3	0.9	0.6	1.9	1.5	0.8	0.49	0.6
FeO	1.2	1.6	3.4	2.6	4.7	2.5	2.30	14.7
MgO	--	0.8	0.7	0.7	0.7	0.3	0.51	3.1
CaO	2.8	2.1	2.1	2.0	3.2	2.1	3.91	6.7
Na_2O	3.6	3.7	3.5	3.0	3.4	2.9	2.35	2.8
K_2O	4.71	5.4	6.9	6.6	5.7	6.4	7.28	3.1
TiO_2	0.27	0.44	0.47	0.45	0.76	0.38	0.33	3.2
P_2O_5	0.08	0.13	0.11	0.17	0.23	0.07	n.d.	0.57
MnO	0.09	0.07	0.07	0.10	0.12	0.08	n.d.	0.16
H_2O	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	99.04	98.84	98.95	98.92	98.91	99.03	99.87	99.23

Norm.

		1	2	3	4	5	6	7	8
Q	=	26.2	22.6	15.2	20.2	10.7	20.0	20.5	3.8
or	=	28.5	32.5	41.5	40.5	43.0	39.5	43.0	19.5
ab	=	33.0	34.0	30.5	28.0	25.5	27.5	20.5	26.5
an	=	5.5	0.5	--	--	--	4.00	5.8	9.3
di	=	--	--	--	--	--	--	--	20.4
ac	=	)--	--	1.2	--	4.4	--	--	--

wo =	5.4	3.2	4.2	4.0	6.4	2.6	5.2	—
fs =	1.6	1.8	5.0	2.6	7.2	3.2	3.2	—
en =	—	2.2	2.0	2.0	2.0	0.8	1.4	—
fa =	—	—	—	—	—	—	—	13.5
fo =	—	—	—	—	—	—	—	3.0
mg =	0.3	0.9	0.2	2.0	0.0	0.9	0.5	0.6
il =	0.4	0.6	0.6	0.6	1.0	0.6	0.4	5.6
ap =	0.3	0.3	0.4	0.4	0.3	—	—	1.-
Total	101.2	98.6	100.8	100.3	100.5	99.1	100.5	103.2

1. ME 11A Biotite Granite, opposite Gurn Hill.

2. ME 136 Biotite Granite (Tara Type) Tara Hill.

3. ME 111 Biotite Hornblende Granite, below
                                    Yelwa School Hill.

4. ME 94 Fayalite Quartz Monzonite Baskin Hill.

5. ME 102   "   "   "   Yelwa Bridge.

6. ME 222   "   "   "   south of Kofar
                                                    Wombai Hill.

7. ME 222A   " ...   "   "   "   "   "

8. ME 133 Quartz diorite North of Kofar Wombai Hill.

(See also Table 10)

Analyses Nos 1 - 6 and 8 by R. P. Hollingworth, Dept.
            of Geology, Science Laboratories, Durham.

and No. 7 by J. Cobbing and W. Layton of the Dept.
            of Geology, Science Laboratories, Durham.

Norm Calculations by the writer, after the method

proposed by T. W. F. Barth (1951, p. 76).

granite and then shows decrease with increase silica,
while Calcium curve tends to show the reverse trend,
both representing some sort of abnormality from the
Biotite Hornblende Granite towards the Biotite Granites.
Between the Fayalite-Quartz Monzonite and the Biotite-
Hornblende Granite, the iron and magnesia curves
indicate an abnormal rise in the amount of these
oxides in the Biotite-Hornblende Granite over the
Fayalite-Quartz Monzonite.

TABLE 7

Optical Data for Fayalite, Pyroxene and Hornblende.

	1	2	3	4	5	6	7	8	9
Z	n.d.	n.d.	1.758	1.742	n.d.	1.709	1.713	1.712	1.712
Y	n.d.	1.731	1.747	1.735	1.716	1.709	1.711	1.712	1.712
X	1.81	n.d.	1.742	1.727	n.d.	1.689	1.692	1.692	1.690
Z-X	n.d.	n.d.	0.016	0.015	n.d.	0.020	0.020	0.020	0.022
2V	−50°	+55°	−83°	−63°	+53	n.d.	n.d.	n.d.	n.d.
EXT	0	47°	0	0	n.d.	n.d.	20°	26°	14°

(X C)

1. Fayalite from Fayalite Quartz Monzonite (ME101)

2. Clinopyroxene from the same specimen above.

3. Ortho-pyroxene charnockitic monzonite (ME102)

4. Ortho-pyroxene from quartz diorite (ME133)

5. Clinopyroxene   "   "   "   " "

6. Amphibole from Biotite Hornblende Granite (ME124)

7.   "   " Fayalite Quartz Monzonite (ME101)

8.   "   " Charnockite variation of "7" (ME102)

9.   "   " Quartz diorite (ME135)

CHAPTER III.   MICRO-STRUCTURE OF THE BAUCHI ROCKS.

Becke, Sederholm, Spencer, Eskola, among many
other petrologists, have given a great deal of
attention to the problem of petrological structures
such as myrmekite and microperthite; since these
structures may in many ways hold the key to petro-
genetic classification of most rocks of indefinite
origin in which they are commonly found.   In this
work, a special study has been made of these
structures because their genesis is intimately tied
up with that of the potash feldspar, a very
conspicuous and important constituent of the Bauchi
rocks.

Myrmekite.

Myrmekite is an intergrowth of quartz and plagio-
clase.   It was first described by Michel Levy about
1874 and the term myrmekite was proposed by Sederholm
a few years later (Anderson 1937).   Myrmekites are of
vermicular structure and when well developed, they
strongly resemble coral growth.   (Plate 32 fig. A)
They commonly appear based on a plagioclase plate,
referred to by some authors as the core, with a convex

front invading the potash feldspar. (Fig.10).

Three stages may be observed: early, late and decline. (Fig. 10) The early stage is marked by a narrow albitic selvedge which grades on the plagioclase side to a finely shredded incipient myrmekite invading the potash feldspar. Later, a stage is reached when two or more of the fine quartz vermicules join, rivulet-like, to form more definite ones. At this stage the front towards microcline has achieved a definite convex outline and the typical myrmekite form has emerged. Finally detached blebs of quartz may then appear to mark the decline stage.

Not uncommonly all three stages may be observed on one large myrmekite area but far more common are combinations of either early and late stages (Plate 32, fig. B)., forming "matured" myrmekite, or late and decline (Plate 33, fig. A) forming "old" myrmekite.

Almost invariably, very old myrmekite is associated with marginal quartz, especially when only the decline stage is present. This marginal quartz is "excretory" being forced out of the plagioclase by its higher force of crystallization. Some plagioclase crystals enclosed in potash feldspar may have only this excretory marginal quartz (Plate 33,

fig. B) to indicate that they are post-myrmekitic.
Thus as it were the growth of the myrmekite is a
process of collecting the quarts together for
expulsion by a plagioclase clearing itself of
inclusions.

Myrmekite is most commonly located at the contact
of microcline and plagioclase where it appears as
inflated cauliflower-like masses into the former.
Nearly all the myrmekite observed in Bauchi rocks is
so localized. Plagioclase enclosed in microcline may
be wholly or partly myrmekitic; commonly they are
not, but post-myrmekitic as shown (Plate 33, fig. B)
and with associated excretory quartz.

A narrow rim of a myrmekite-like body is often
observed at the border of quartz with microcline,
and a chain of myrmekite may be located at the
contact of two microcline crystals or fracture line
in a crystal. In no case is myrmekite observed on
plagioclase which is not contiguous with microcline
except where such relationship with a microcline
could be inferred. In all cases the size of the
myrmekite is subordinate to that of the microcline
with which it is associated.

In the Bauchi rocks myrmekite occurs in all

rocks in which potash feldspar is present, except
the Quartz Diorite and it becomes progressively
abundant with increasing microcline content,
indicating some quantative relationship with the
microcline. (Fig. 19)

There is widespread agreement among petrologists
on certain characters of myrmekites some of which
the present writer has also observed. As stated by
Sederholm (1916), most authors agree that myrmekite
is almost always invading microcline and a core or
"pedestal" of plagioclase is invariably present or
inferrable. (The term "pedestal" is proposed for
the plagioclase on which the myrmekite is sitting.
This term is more descriptive of the relationship of
the myrmekite to the plagioclase, sitting on it as
it were. The writer objects to the term "core"
because this term may suggest that the plagioclase
is of inner or central part of the myrmekite and one
with it, whereas the plagioclase on which this
structure is rested, as will be shown, is necessarily
primarily crystallized before the myrmekitization.
Some authors have observed contrary features, for
example, Eskola (1914) claimed to have observed
myrmekite with a rectilinear boundary against

microcline. As was noted by Sederholm (1916), these contrary observations are so rare and easily explained that they do not invalidate the generally accepted characters of myrmekite as stated above. Myrmekite with such rectilinear boundary against microcline is not observed in any of the Bauchi rocks; however, such rectilinear boundaries against microcline could very well be attributed to the later truncation of the myrmekite by the microcline.

Spencer (1945) in agreement with Barth observed that there is commonly a decreasing basicity from the core (pedestal) to the rim and that the plagioclase of the myrmekite is generally more acidic than the primary plagioclase. In the rocks of Bauchi this tendency has been observed but it is not uncommon to find some myrmekite which has plagioclase uniform in composition through to the pedestal.

Spencer (1945) further observed the scarcity of myrmekite in pegmatite microcline and in orthoclase of soda syenites, but in the rocks in which they occur, as Sederholm (1916) observed, myrmekite is usually widespread but is never large enough to replace a whole microcline. The study of myrmekite in Bauchi rocks confirms this.

Origin of Myrmekite.

Becke (1908) who first made an elaborate study
of myrmekite concluded that in the ~~pr~~ replacement
of potash feldspar by plagioclase, the albite
replaced the potash feldspar molecule for molecule,
but the anorthite portion, on replacing potash felds-
par, yielded four molcules of quartz. He justified
this by showing that the proportion of quartz to
feldspar in a myrmekite is always within what might
be expected from such origin. This has since been
the most acceptable explanation of myrmekite and
explanations given by Eskola, Sederholm and Spencer
given below have used it as the basic assumption.
This explanation appeared to satisfy all the different
structures and characteristics of myrmekite described
above, but in the Bauchi rocks in which myrmekites
are most common a late-stage soda-lime metasomatism
is most unlikely and does not appear to have occurred.
Rather, a late stage potash metasomatism appears to
have taken place.

Schwantke in 1909 (Spencer 1945) suggested that
some lime feldspar are held in solution in potash-
soda feldspar in the form $Ca(AlSi_3O_8)$. He found
that analyses of alkali feldspars showed excess

silica and deficient feldspar. Schwantke therefore
concluded that on seperation the lime feldspar would
take its usual form releasing silica. Spencer (1945)
examined more recent analyses and showed in support of
Schwantke's that potash-soda-feldspars show excess
silica. Even though this is a very tempting solution,
the localization and distribution of myrmekite in
Bauchi rocks cast much doubt on the role of such
high silica feldspar in the formation of myrmekites.
Myrmekites should, for instance, have been more
abundant enclosed in alkali-feldspar, especially in
those of pegmatite, rather than invading.

Eskola (1914), agreeing with Becke, maintained
that the rectilinear boundaries against microcline
he observed associated with the ordinary curved
myrmekite was an/idiomorphic form which originated
during the processes of consolidation. No rectilinear
myrmekite was observed in the Bauchi rock and such
primary crystallization of myrmekite seems most
doubtful.

Sederholm (1916) believed that myrmekites were
formed by a late magmatic phenomenon which he termed
"deuteric action". Before the final consolidation

of the rock, solution and gases circulating from
neighbouring or distant parts of the rock caused
replacement of potash-soda feldspar by lime on the
line postulated by Becke. He maintained that material
from without must be available. Applied to the
Bauchi rocks, Sederholm's explanation encounters
the same difficulty as that of Becke, on which it is
based. In addition such late-stage circulation of
gases and solution if causing a lime metasomatism,
should form a reaction rim of myrmekite round some
albitic plagioclase. This explanation will not
satisfactorily explain the "pedestal" plagioclase
which appears to be essential in the formation of
myrmekite.

Anderson (1937) stated that myrmekite appeared
to have been formed "as an accompaniment of
replacement of potash feldspar by plagioclase" in
agreement with Becke's theory which he considered
the best substantiated and most widely accepted
explanation. He showed by their occurrence "in
contact zone in partly re-crystallized rocks, which,
beyond question, never were molten," (p. 9) that
myrmekite was not invariably due to magmatic
crystallization. He did not indicate the source of

this replacing plagioclase, but, he first divorced
myrmekite from late magmatic activity.

Drescher)Kaden (Bugge 1943) thought that
myrmekite was formed by replacement action related to
the formation of potash feldspar paving the way for
the conclusions of Edelman (1949) that a K - Al
metasomatism causes a Ca-Na-Si metasomatism. His
equations for these process are given below.

$$I \quad K^{\ddagger} + Na\ Al\ Si_3O_8 = K\ Al\ Si_3O_8 + Na^+$$

$$II \quad K^+ + Si + Ca\ Al_2Si_2O_8 = K\ Al\ Si_3O_8 + Ca^{++} + Al^{+++}$$

$$III \quad K^+ + Al + 4\ Si\ O_2 = K\ Al\ Si_3O_8 + Si^{++++}$$
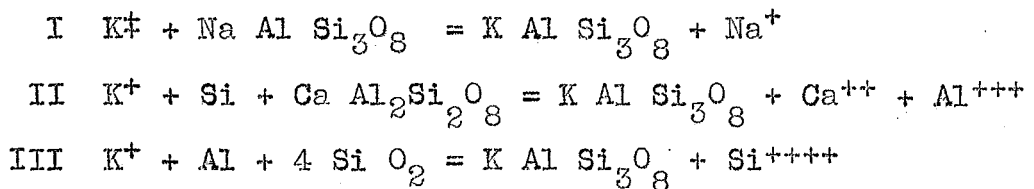
The Na^+, Ca^{++}, Al^{+++} and Si^{++++} thus provided
caused a reversed reaction in some other parts of the
rock thus forming myrmekite according to Becke's
theory. He maintained that there was a quantitative
relationship between microline and the myrmekite
fringing it and concluded that myrmekite was formed
by and contemporaneous with granitization.

Most authors as seen from above review, accept
Becke's theory in principle but differ over the source
of soda-lime necessary to replace potash for the
formation myrmekite. In the rocks of Bauchi, the
microcline appears to be replacing other minerals,
lobing into them and embaying them. Some of these,

minerals, especially the plagioclase, show strain,
while the microcline show no evidence of such
deformation. The order of formation is therefore
plagioclase, microcline and finally, the myrmekite.
In truly magmatic rocks an alkali-rich phase is the
more reasonable end of crystallization. Concentration
of soda and lime over potash cannot be widespread in
the late magmatic stage to cause large scale
myrmekitization. This accounts for the invariable
absence of large scale myrmekite association with
orthoclase.

The suggestion by Drescher-Kaden (Bugge 1943)
that myrmekite was formed by replacement action
related to the formation of potash feldspar is more
in accordance with the writer's observations of
myrmekites in Bauchi rocks. Endelman's hypothesis
(1948) and the reaction equations given by him
partly explain the myrmekite in these rocks, except
that he has not explained the role of the "pedestal"
in the formations of myrmekite.

Endelman's (1948) equation should be modified
as follows:

IV: $2K^+ + Ca\,Al_2Si_2O_8 + 4\,SiO_2 = 2K\,Al\,Si_3O_8 + Ca^{++}$
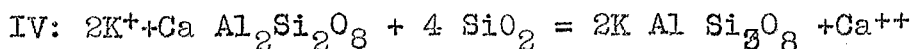
This reversible reaction is controlled by the

concentration of cations, since, in whatever phase
the reaction is taking place, certain minimum
concentration wuould be expected for either Ca^{++} of
K^+ before the reaction takes place one way or the
other.

In microclinization, soda and lime are being
released both of which are soluble to a limited
extent in microcline. This generation of Ca^{++} and
Na^+ would accelerate rapidly when a plagioclase is
being replaced by a microcline and in most cases the
critical concentration of Ca^{++} and Na^+ relative to
K^+ would be reached and thus the reverse readtion
would be initiated with the consequent formation of
myrmekites due to simultaneous production of quartz
and feldspar. Once this reverse reaction sets in,
it attracts more soda and lime from the surroundings
where microclinization is in progress and exchanges
potash for them according to the concretion principle
of Eskola (1932). Thus a potash feldspar may build
itself in one direction at its own expense. It is
also conceivable that the microcline being now
replaced by soda-lime feldspar would seize the
opportunity to unload itself of excess soda and lime.
Thus the plagioclase initiated the growth of myrmekite,

and acted as the pedestal for this "petrological"
coral" but does not aid its growth once initiated.

Microclinization may continue on both sides of
the growing myrmekite, supplying it with more material
for its own growth, and eventually the microcline may
enclose the myrmekite as occasionally observed. Less
commonly, a fluctuation to a more vigorous micro-
clinization would cause the myrmekite to be replaced,
thus may be formed a truncated myrmekite with
rectilinear boundary observed by Eskola (1914.)

As soon as the myrmekite is formed and growing
the process of "quartz-clearing" by the plagioclase
brings the quartz together as described earlier. In
prolonged metamorphism, such as is essential for the
replacement formation of microcline porphyroblasts,
many crystals have successfully cleared themselves
of quartz and whether poikilitically enclosed or not
the excreted quartz is commonly found in its typical
association with the plagioclase which has gone
through the complete cycle of myrmekitization, (Plate
33, fig. B).

The myrmekites in Bauchi rocks are formed in
this manner, and whether they are subsequent and
consequent to microclinization or a late stage action

in magmatic crystallization they are essentially a
product of subsolidus phenomenon. Their abundant
and even distribution through all the members of
Bauchi rock complex rich in microcline rules out a
late stage magmatic action, and the widespread
evidence of decline myrmekitization is suggestive
of replacement under the condition of a prolonged
dynamo-thermal metamorphism, as the origin for the
microcline.

Perthites

Perthite was originally defined in 1843 by
Thomas Thomson as the parallel intergrowth of
orthoclase and albite, but the term has been since
extended to include all sorts of irregularly shaped
intergrowths of potash feldspar and plagioclase
(Anderson 1937). Various types are now recognised.
Anderson (1928) made a systematic study of
perthite and/recognised several textural types;-
string type, film type, vein type, and patch type.
Alling (1932 and 1938) has proposed many generic
types, not favoured by the writer since most of these
are already covered by Anderson's (1928) textural
types. Two of Alling's (1938) textural types,

stringlets and rods, are not covered by Anderson's and are used together with Anderson's to classify the perthites in the Bauchi rocks.

The varieties encountered in Bauchi rocks include the following: The stringlets which are of very fine blebs just barely resolved under the low powered (X5) objective. They are frequently oriented parallel to (100) and often give the host feldspar a velvety texture (Plate 34, fig. A). The perthite in the Quartz-Diorite is finer still and may be called "sub-stringlet".

The string type appears to be formed by the union of two or more stringlets. The blebs are long needles about 0.03 to 0.1 mm. in length and in width average about 0.01 mm. (Plate 34, fig. B). The orientation is as for stringlets.

The film type is of thin lamellae, longer and broader than string type and, contrary to Alling (1938), sharply outlined (Plate 35, fig. A). They are oriented parallel to (001).

The rod perthites (Plate 35, fig. B) are most likely a special section of the film type or the vein perthite. The vein perthites are of coarser and longer blebs and are oriented parallel to (100).

Though maintaining this general orientation they branch irregularly (Plate 36, fig. A) The less coarse type which might be called veinlet (Plate 36, fig. B) is termed "Streak" by Anderson.

The patch perthite (Plate 37, fig. A) is formed by patchy plates of plagioclase in the potash feldspar. These blebs tend to be elongated at right angle to the length of twin lamellae and not uncommonly these optically continuous patches are connected by blebs of the vein or string type. A type of patch perthite in which the blebs are more like inclusions (37 fig. B) may be called "poickiloperthite". The blebs may be optically continuous with a larger grain of plagioclase contiguous and sutured with the host potash feldspar. In this type, it is not unusual to find one of the blebs optically discontinuous, and there is no elongation in the direction perpendicular to the lamellae as in the patch type.

When a plagioclase host contains blebs of potash feldspar it is termed an antiperthite (Plate 38, fig. A). The blebs form irregular patches and are themselves perthitic (Plate 38, fig. B) thus forming a compounded-perthite.

Distribution in Bauchi Rocks.

The stringlets are found mostly in the Fayalite-Quartz Monzonite and the substringlets in the Quartz-Diorite. The string, film and rod perthite are most common in the Biotite-Hornblende Granite and the Biotite Granite. The vein perthites are associated with pegmatites and the patch perthite with strained porphyroblasts. Poikiloperthite and Antiperthite occur almost exclusively in the Quartz Diorite but are rarely observed in the Fayalite-Quartz Monzonite.

Some characteristics of perthites:-

On heating perthite of average bulk composition at about 850° or lower temperature under condition of high (H_2O) pressure, for a few hours the feldspars become gradually homogenized (Spencer 1937 and 1938) possibly passing successively through cryptoperthite and "X-ray" perthite stage. On being slowly cooled the feldspars unmix again to give a perthite feldspar. "Low temperature cryptoperthites having composition near $Ab_{50} Or_{50}$ refused to mix compleltly on heating near the liquidus (Tuttle and Bowen 1958). Chayes (1952b) demonstrated the effect of stress on perthite and concluded that shearing stress favour if it did

not actually induce unmixing of the feldspars to
give perthites. The writer's experience with the
cataclastically deformed rocks of Bauchi supports
Chayes' suggestion. The "augen" frequently develops
much coarser perthitic structures than the microcline
of the undeformed rocks, but at an advance stage of
cataclastic deformation the effect appear negative.

Alling (1932 and 1938) has variously emphasized
the effect of inclusions on the perthite blebs.

In the Bauchi rocks, the perthite blebs may
become definitely more abundant around a plagioclase
inclusion or any other inclusion in the potash
feldspar, but they may also avoid margins of such
inclusions creating a barren halo round them, and
most frequently they ignore inclusions completely.
Perthites of relatively high temperature rocks tend
to be very fine with sub-stringlet perthites and
cryptoperthites, while perthites associated with low
temperature rocks such as simple pegmatites are the
coarser, less regular vein type of perthites. However,
rocks originally crystallized at high temperature and
slowly cooled in the presence of water vapour may
develope coarser types of perthite blebs than those
in the string type. (Bowen and Tuttle, 1958).

Anderson (1928) recognised this temperature control
of perthite and his textural classification used
above represents condition of decreasing temperature.
The distribution of the various types in Bauchi
rocks may thus indicate successively lower temperature
condition from the Quartz-Diorite to the Biotite
Granite.

The Origin of Perthite.

Four main theories have been proposed to explain
the origin of perthites in rocks: exsolutions,
simultaneous crystallization, replacement and
solution filling.

The exsolution theory has appealed to many
petrologists as an explanation of perthite and today
it is probably the most accepted and the most
substantiated. The principle of exsolution has been
the subject of various types of phase diagrams.
Those of Bowen and Tuttle (1958) and Laves (1952)
(fig. 11) are the most recent. According to these
diagrams, when first crystallized, potash feldspar
carries in solution an amount of soda feldspar which
it could hold at that temperature, and with cooling,
it continuously adjusts the amount it holds in

solution to the falling temperature by exsolution
and thus perthite is formed. All the characteristics
of Bauchi perthites discussed earlier can be explained
by this theory and it is also justified by the
consideration of the mutual solubility of $Na\ Al\ Si_3O_8$
and $K\ Al\ Si_3O_8$. Most of the perthites in the Bauchi
rocks, other than some vein and patch types were most
likely formed on this principle. Warren (1915) made
a quantitative study of feldspar, and concluded that
those perthitic feldspars with more than 28% albitic
plagioclase, which could not have been formed by
unmixing of a previously homogeneous feldspar, are
formed by "original intergrowth". Though he appeared
to have changed his opinion later (1945), Spencer
(1938) suggested the term cotectic-perthites for
vein perthites and claimed that they were formed by
simultaneous crystallization. Simultaneous
crystallization, limited to perthites in low
temperature rocks like pegmatite, seems a valid
conception. That the albite component of most
perthitic pegmatite is far in excess of what they
could previously have held in solution, make this
mechanism probable. The Bauchi pegmatites appear
to have been emplaced either by direct crystalliza-
tion from very low temperature solution or by

replacement process. In either case, relatively low temperature high pressure condition must have prevailed over a long period. Under such condition, intergrowth by simultaneous crystallization appears a reasonale explanation. Attempt to attain equilibrium must have caused the feldspar to rearrange themselves by diffusion into a form which imposes the least strain on the lattice thus giving the usual vein perthite form. Here there is no limit to the proportion of soda to potash feldspar and the emphasis is on the feldspar being ordered to equlibrium.

A replacement has been claimed by many petrologists for certain perthite (Schaller 1926, Anderson 1937). In the Bauchi rocks the patch perthite, poikilo-perthite and antiperthite could have been formed by pseudomorphic replacement processes, but the augen gneisses in Bauchi district demonstrated that some patch perthite might be formed by exsolution under the influence of stress.

Anderson (1928) suggested that certain perthites are formed by recrystallization in contraction cracks. This is considered an unlikely origin of perthite in general. It is, at least, not supported by the

characters of perthites in Bauchi rocks. One would
wonder why such cracks are not sometimes filled by
other minerals, say quartz.

Perthitic Porphyroblasts.

It appears that the large microcline crystals
formed under metamorphic condition by replacement in
solid rocks could be perthitic. The solubility of
$Na\ Al\ Si_3O_8$ in $K\ Al\ Si_3O_8$ is a function of temperature
and the diffusion of Na and K is equally dependent on
temperature. As shown in the equations by Endelman
(Equations I-II) considerable amounts of soda and
lime are released as a result of potash metasomatism
during the formation of the porphyroblast, and some
of this soda and lime will diffuse through the
porphyroblasts and, depending upon the temperature,
an amount may be held in solution. On cooling the
attempt by the crystal to maintain equilibrium
according to the principles explained by Laves (1952)
will result in unmixing and consequent formation of
perthite. Such perthite would hardly be distinguish-
able from that formed by phenocrysts crystallized
directly from magma. However where the thermal
condition has not been maintained over a sufficient

period of time the diffusion may not be thorough and
the soda and lime content of the potash feldspar would
be uneven, higher in the immediate area where a plagio-
clase has been replaced and low where, say, quartz
has been replaced.   Such, on cooling, would unmix to
give unevenly distributed perthite blebs these being
clustered in areas of high soda-lime content and
sparse in areas of low soda-lime content.   Though one
would hesitate to say that such uneven distribution
of belbs could not occur in perthites of magmatic
origin, it is considered rather unlikely.

Origin of the Perthite in Bauchi Rocks.

Of the various origins proposed for perthites
the most acceptable and the best substantiated in
Bauchi are those which are based on the principle of
"unmixing" (exsolution).   Unmixing as a phenomenon is
the attempt of soda-potash feldspar to attain
equilibrium on the line explained by Laves (1952)
(ordering of Al and Si, and the unmixing of K and Na.)
This follows from the difference in the atomic sizes
of K and Na which renders them only limitedly mutually
soluble at the low temperatures.   Perthites formed on
this principle should be regarded as true perthite.

These, even when irregular as in the vein type or
Anderson's streak type, have an overall uniformity of
pattern an orientation characteristic of it such
being dictated by the rate and length over which
exsolution has taken place, the presence or absence
of water vapour, the bulk composition and structure
of the host feldspar and to a less degree by the
magnitude of shearing stress; many of these variables
are interdependent.

In deep seated Pre-Cambrian rocks, such as the
Bauchi granites, which are of uncertain petrological
history, distinction could hardly be made on the basis
of the type of perthite, between a rock of direct
magmatic origin and one which has been formed by
metasomatism and granitization. As shown above a
porphyroblast may develope perthitic blebs quite
similar to those of phenocrysts crystallized from a
magma, since the principle is the same. Where the
perthite blebs have a tendency to be irregularly
clustered and are of non-uniform proportions from
grain to grain, one may begin to suspect, with
reservations, that the rock was of replacement
origin. Applied to the Bauchi rocks, the Quartz-
Diorite would appear to have had relatively a higher

temperature origin. The Fayalite-Quartz Monzonite
and the Biotite-Hornblende Granite with stringlet
and string type of perthites which are irregularly
clustered and distributed, the potash feldspars were
probably formed by replacement at fairly high
temperature, while those of the Biotite Granite,
with coarser but irregularly distributed blebs, have
possibly been formed by replacement under the
conditions of prolonged dynamo-thermal metamorphism,
such as must have favoured the development of the
pegmatite dykes with bold vein-perthitic blebs.

The Pseudocataclastic Structure.

The term pseudocataclastic structure was proposed
by Anderson (1939) to describe a sugary to fine mosaic
aggregate of minerals surrounding the large crystals
of feldspars and forming a texture which is similar
to that of cataclastically deformed rocks.

A similar texture has been observed in some
sections of the Bauchi rocks. (Plate 39 fig. A) That
they may not be related to true cataclastic structure
is shown by the following characters of the texture:-
They follow the outline of the larger minerals which
frequently are sharply angular, unlike the rounded

augen in cataclastic rocks with the granulated
material sweeping round them. Their mineral
aggregate is quite different from what would be
expected if they were ground off from the larger
crystals in their immediate vicinity and the quartz
grains are not as elongated as would be expected
from a cataclastic rock.

The Minerals of the Pseudocataclastic Structure.

In the Bauchi rocks the mineral principally
forming this structure are quartz and plagioclase
in a fine granular aggregates with the latter the
more abundant. Some small amount of microcline may
be present. Frequently, the minerals form a very
fine sugary-textured mass in which the individual
minerals cannot be identified, but which soon grade
into a mosaic of larger grains. The plagioclase is
oligoclase. The quartz occurs as small grains, verm-
icules and blebs corroding the feldspars, and masking
the granular texture. Microcline is rather variable
and is frequently absent in the aggregate. Where the
structure adjoins a microcline it may be festooned by
a chain of myrmekite.

The Distribution and Origin of the Pseudocataclastic Structure.

The pseudocataclastic structure is most abundant in the Biotite Hornblende Granite, least common in the Fayalite-Quartz Monzonite and not found in the Quartz-Diorite.

Anderson (1937) attributed this structure to late stage solution effects in which secondary material was introduced along the boundary of the larger minerals which were corroded as the vein-like mass widened. This is not the case in the Bauchi rocks. The fringe of myrmekite, along some of the veins, as concluded from the study of myrmekite suggest that the microcline was replacing the minerals of this structure. Such a late-stage solution effect is admittedly possible in the Bauchi rocks.

Where the veinlike aggregate is wider (Plate 39, fig. A) the similarity to the ground mass of a fine grained Biotite Granite is striking. It is therefore probable that the structure is formed by narrow zone of relic mineral remaining between two advancing porphyroblasts. In some instances (ME 140, plate 39, fig. B), the pseudocataclastic structure could represent the relic of what was actually a cataclastic ground mass.

Thus this structure further points to replacement as the probable origin for the large microcline of the Biotite-Hornblende Granite.

Zoning in the Plagioclase.

Normal zoning is commonly observed in the plagioclase of the Quartz-Diorite, and this tendency is also noted in those of the amphibolite. The zoning in the quartz diorite is of an inner core of calcic andesine with an outer zone of more albitic andesine. The crystals are anhedral and are usually lobed into by the surrounding ferromagnesian minerals (Plate 28, fig. B).

Normal zoning is commonly held to be a magmatic phenomenon. In all cases it is interpreted as representing unstable condition in the magma chamber, (e.g. Phemister, 1934).

Dunham (1958) mentioned a case of zoned andesine-oligoclase feldspar in amphibolite from Sierra Leone, "which could not, because of the textural relations, be other than of metamorphic origin" (p. 8.) Through the kindness of Professor K. C. Dunham the writer has been able to compare the zoning in the plagioclase of these Sierra Leone amphibolites with those of the

Quartz-Diorite and the amphibolite from Bauchi. They all have a characteristic vagueness of definition. The zoned feldspar of the Quartz-Diorite show better defined cores which are very irregular and they may have more than one core in a crystal. (Fig. 12) These characteristics of the zoning in the plagioclase of the quartzdiorite are difficult to explain by any theory based on instability or changed conditions in a crystallizing magma but may be explained either by magmatic resorption effect, or else by metamorphism.

Origin of Zoning in the Feldspar of Bauchi Rocks.

Plagioclase zoning commonly accepted as a magmatic phenomenon is not necessarily such. As proved in the plagioclase of the amphibolite from Sierra Leone, zoning can be induced in plagioclase by metamorphism under conditions of amphibolite facies. Magmatic zoning is more sharply defined, frequently oscillatory and are in outline subhedral to euhedral. Those less sharply defined zoning, especially with irregular or disjointed cores, are probably not of magmatic origin. The zoning in the plagioclase of the amphibolite might have originated by exchange of lime for soda, the plagioclase losing the lime to the growing hornblende

by ionic diffusion in solid or vapour phase. The
zoned plagioclase of the Quartz-Diorite with the
disjointed and irregular cores could be due to
resorption or otherwise to loss of lime to the
pyroxenes and hornblende by metasomatosis.

Checkerboard Structure.

The (?) calcsilicate rock specimen (ME 137) from
near the air strip, which may be called a pyroxene granulite
~~granite~~ contains abundant plagioclase with a peculiar
checkerboard structure (Plate 40, fig. A). This
structure is formed by rectangluar to cubic blebs of
a mineral of much lower refractive indices than the
host plagioclase. The bleb mineral is believed to be
a plagioclase feldspar because the twinning, in some
cases, appear to be continuous across it and of
oligoclase compostion from its parallel extinction.

This checkerboard structure is believed to
originate by exsolution of albite from the host
feldspar, resulting from the necessity for the latter
to adjust its composition to high temperature and
pressure condition of metamorphism.

CHAPTER IV. EVIDENCE FOR THE GENESIS OF BAUCHI ROCKS.

Bain (1926) who was the only person who had
previously studied the rocks of Bauchi in great detail
concluded, that the Bauchi "granites" were intruded
bodies. He suggested three periods of intrusion, as
shown in Table 2. He claimed that a long period of
quisence prevailed before the last intrusive phase,
so that the Bauchi Granite series and the fine grained
Biotite Granite series formed two major intrusive
cycles. He claimed further that the Bauchi Granites
differentiated in place into two types, Pyroxene
Syenite and Hornblende Biotite Granite corresponding
to the Fayalite-Quartz Monzonite and the Biotite-
Hornblende Granite of this account.

Bain did not mention any evidence in support of
this view, but those features could have led him to
conclude that the Bauchi "granites" are intrusive and
differentiated in place can be readily appreciated in
these rocks.

Evidence for Magmatic Origin of the Bauchi Granites.

The rocks of the Bauchi Batholith, the later
intrusion, are Quartz-Diorite, Fayalite-Quartz and
Biotite-Hornblende Granite. They form a gradational

series and could have been formed in place by differentiation from a common magma. From the composition of the three principal members of this series, a diagramatic representation of the course of differentiation has been constructed (Fig.13) In the plagioclase, there is a progressive increase of Ab ratio, and in the pyroxenes there appears to be a progressive increase in theFe/Mg ratio as would be expected of a differentiated body. Such variation in soda and iron is however not necessarily due to differentiation as will be shown subsequently.

The Quartz-Diorite member of the series frequently shows normal zoning in the plagioclase. As shown in the preceding chapter, this may be regarded as a magmatic phenomenon, even though similar structures may be produced or preserved in metamorphic rocks as demonstrated by the amphibolite from Sierra Leone (Dunham and others 1958, p. 8) and the amphibolite from Bauchi (ME 206).

According to Buddington (1948) the phenocrysts of a porphyritic rock crystallized from a magma are usually well formed. Superficially the large microcline crystals of the Bauchi Granites are strikingly well formed, and their arrangements very regular, so

that as seen over a large area they make patterns of
wall/paper regularity. Moreover, the linear
distribution of these large crystals in the Biotite
Granite could suggest the effect of magmatic flow.

The contacts of the Bauchi Batholith series with
fine grained biotite granite, rarely seen, are some-
times sharp though not chilled at the margins. The
absence of chilled margins could be attributed to
the intrusion having taken place at great depth so
that the country rocks were hot when they were
invaded.

The large inclusions of fine-grained dense rock
found in the Bauchi granites (Plate 5, fig. A),
could be xenolithic blocks of biotite granite which
were immersed in the magma during stoping and
subsequently recrystallized.

The Medium-grained Biotite Granite resting
partly on the Quartz-Diorite and partly on the
Fayalite-Quartz Monzonite resembles a recrystallized
roof pendant. The Fayalite-Quartz Monzonite in its
western margin contains relict granulite which has
been recrystallized and appears hornfelsic.

These and perhaps a few other lines of evidence
could be evoked to suggest that the Bauchi granite

series was a product of differentiation of a magma
in place. If such an origin were assumed, certain
features of the rock present considerable difficulties;
these are discussed below.

The Possible Nature and Origin of the Magma.

A magma differentiating in place to give the
Bauchi Batholith series would not be very basic
and at least less basic than the Quartz Diorite,
the most basic member of the series, except if there
are more basic members of the series still unrevealed.
It would also have to be somewhat less acidic than
the Biotite-Hornblende Granite, the most acid member.
The Fayalite-Quartz Monzonite and the Biotite-Horn-
blende Granite which made up about 98% of the rocks
in the series are composed on the average of
microcline perthite 51%, plagioclase 25%, and quartz
16%, the remaining 8% being fayalite, hornblende,
biotite, apatite and ore. The magma of the present
Bauchi rocks would therefore have had to have been
very rich in the constituents of microcline, inter-
mediate plagioclase and quartz at the beginning of
differentiation, even if it were originally more
basic, and would probably be chemically about the

composition of the Fayalite-Hornblende Granite (table 9).

The presence of fayalite suggests that the magma was dry. From the absence of chilled margins, when the contact is a sharp line, it can be inferred that the surrounding rock must have been nearly as hot as the invading magma. By the absence of evidence of partial fusion of this wall rock this temperature could not have exceeded 1025°.

The viscosity of a silicate magma at a given temperature can be estimated from the viscosity which is characteristic of its components (Vogt. 1923). The magma which would give Bauchi granites as shown earlier is very largely of K AlSi$_3$O$_8$, Na AlSi$_3$O$_8$, Ca Al$_2$Si$_2$O$_8$ and SiO$_2$ components (92%); with the exception of Ca Al$_2$Si$_2$O$_8$ which is of medium viscosity, these components are extremely viscous even when heated some hundred degrees above their melting temperature, (Vogt. 1923, Bowen and Tuttle 1958 p. 77). Since the magma would be dry as shown earlier it would be more viscous than average granite magma. Granitic melts are extremely viscous even when heated as much as 300% above the temperature of crystallization (Vogt. 1923). According to the same author the effect of pressure

would have been to increase this viscosity.

In conclusion, one must assume that the Bauchi Magma if there were one would most likely be potash-rich, of a temperature not above 1025°, poor in volatiles, especially water and extremely viscous. Such dry granitic magma would hardly be fluid (that is it should be crystallized) at the probable temperature and it is therefore doubtful if it could exist. If it could, it would be unlikely to crystallize into rocks of such extreme coarseness as the Bauchi granites even given a considerable length of time; for an efficient diffusion of material is hindered in such dry, viscous material. Hypothetically, the most that could be expected of such magma is intermediate grain size. (Vogt 1923). The coarseness could of course be due to later recrystallization by metamorphism.

There is the additional difficulty of generating such a magma. If it could be derived it Might originate in the following ways:- Differentiation and fractiona-tion of a primary basaltic magma according to Bowen's theory, selective fusion of rocks at depth (Anatexis) according to Eskola and Sederholm, or wholesale fusion of some previously existing rock or rocks of granite

composition ------ Palingenesis. (Sederholm and Daly).

Considering Bowen's theory of deriving granitic magma from a primary basalt magma, the argument in its favour and the serious objections to it are too well known and thoroughly discussed to be reiterated. It is sufficient to say that the large extent of Bauchi "granites" and the total absence of basaltic rocks makes that source doubtful for deriving the magma of the Bauchi granites. Bowen and Tuttle (1958 p. 124) suggested the derivation of granitic magma from andesitic liquid derived from partial melting of basalt. In their own words, the process is as follows: " ...... at depths of 35-40 km. basalt could become partially liquid and the liquid would have a composition not far from that of andesitic rocks. If the unmelted portion then settled out, and the andesitic liquid, displaced upward, crystallized in an environment where an opportunity for settling of crystals still prevailed, liquids of granitic composition could result."

This will not yield more granite, possibly less than that from fractional crystallization of basalt magma. It is doubtful whether fractional melting of basalt will yield a liquid in any way near andesite.

Rocks are not molecular but mineral aggregates. Most
of the soda, potash and, especially, silica in basalt
are locked up in minerals which will not release them
until completely melted. Gorasson's experiment (1932)
suggests that partial melting of rocks does not mean
fractional melting.

The minerals of granites have the lowest melting
or crystallization temperature of all igneous rocks
(Vogt 1923),as also can be deduced from their eutectic
position. Thus granite magma of the composition of
the average of the Bauchi Granite series can
conceivably be generated by partial fusion of the
low melting materials of granitic rocks and the
squeezing out of these melted materials during
orogenic movements - differential anatexis (Eskola
1932). The various ways in which this couldbe generated
were described by Eskola (1932a, 1932b, 1933) and Daly
1933. Such a pore magma if dry would be very viscous,
andwould require much higher temperature, the neéessary
amount of water to bring it to reasonable viscosity
and temperature of melting is normally sufficient to
cause complete fusion of granitic rocks. (Goranson 1932)
Thus partial fusion of rocks near granite composition
is unnecessary and partial fusion of diorite is open

to the same objection as Bowen and Tuttle's Andesitic magma.

Daly (1933), Sederholm (1933), Kennedy and Anderson (1936) have shown the various ways in which granitic magma could be derived by wholesale fusion of part of the granitic layer during orogenic mountain building. According to Daly's hypotheses (1933), during mountain building the Sial is downwarped and founders into the substratum with consequent rising of vitreous basalt, the mountain root being thus invaded by basaltic magma. "The deeply sunken blocks, and slabs of sialic rocks" are melted after a considerable time. This he termed "abyssal palingenesis." Some of this abyssal palingenetic magma is taken into solution by the hot basalt but most rises to the bottom of the mountain where, if it is more basic than granitic composition, there may be differentiation. It is known from Geophysical evidences that the Sima is not a liquid and the foundering of the Sial is improbable. Kennedy and Anderson (1936) with much petrological and geophysical evidence in support of this principle emphasized that such primary fusion of the granitic layer could only take place in orogenic areas. There is hardly any doubt that granite magma

could be formed from such abyssal palingenesis, but modern experimental work (Bowen and Tuttle, 1958, Fyfe and other, 1958) indicates that water and fluxing volatiles are needed, and we have no evidence of these in Bauchi rocks other than a little tourmaline, and the dry nature of the Bauchi rock has been demonstrated.

The Differentiation of the Bauchi Magma.

The differentiation of a granitic magma to give rocks of such contrasting composition and texture as the Quartz-Diorite, the Fayalite-Quartz Monzonite and the Biotite Hornblende Granite is another problem. If the magma were, as summed up earlier, viscous, not of exceptionally high temperature and of low water content, its ability to differentiate into such rocks is doubtful.

If it could differentiate, the course of differentiation would be as shown diagramatically (Fig. 13). The abrupt change from crystallization of Ferrohypersthene and Ferroaugite to Fayalite and Ferrohedenbergite is not quite understandable, but is accepted as probable. The main difficulty is the mechanism of effecting such differentiation.

Daly (1933) treated exhaustively all the important

mechanisms by which a magma could differentiate. These
are, fractional crystallization, resorption, liquid
immicibility, diffusion of molecules and ions, pure
melting and differentiation. It is not intended to
discuss these various mechanisms elaborately but only
in so far as they are related to Bauchi rocks.

Bowen's work has established fractional
crystallization as one of the most accepted mechanisms
by which a magma can differentiate. His well known
reaction series summarised this theory of differentiation.
Since the magma had presumably differentiated in place
seperation had to be by either gravity or convection
currents. It is doubtful if the densities and the
crystallization temperatures of the different minerals
involved are sufficiently different to allow these to be
effective in a viscous magma.

According to Daly (1933), as crystallization
begins along the walls the early crystals will sink
and, if the temperature is suitable, they would be
resorbed as they pass through the part of the Magma
with higher temperature. Thus there would be three
different liquids of contrasted densities: "magma yet
unaffected by crystallization, magma modified by
re-solution of crystals sunken into it and magma

residual from partial crystallization". He suggested
that the effect of gravity would prevail over their
miscibility and they would be arranged according to
densities and would be crystallized before diffusion
can effect uniformity. This Daly called differentiation
by resorption.

Since the early crystallized minerals are those
of higher densities and basicity, then the initial
magma modified by re-solution of sunken crystals must
be more basic and denser than the magma yet unaffected
by crystallization and since the former lies above
the latter, it must displace the latter gravitatively.
Such displacement is doubtful in two very miscible
liquids slowly brought together.

It seems more probable that the continued
re-solution of early minerals in the deeper part of a
magma will cause a gradual lowering of temperature
in that part and as soon as the crystallization
temperature of these early minerals is again reached
they will be reprecipitated to continue their journey
towards the bottom of the magma chamber. This will in
no practical way be different from gravitative
seperation in a fractional crystallization. Thus
Daly's "rest magma versus magma of resorption" (1933)

is an unnecessary recasting of Bowen's "fractional crystallization" theory, which has been discussed in the preceding paragraphs. It is not considered a probable mechanism.

Bowen (1928) has considered the role of liquid immiscibility and advanced powerful arguments against it. The mechanism as a means of magmatic differentiation is now taken to be a "Speculation" with very "little direct sanction" (Daly 1933). In relation to the magma of the Bauchi Batholith it can completely be ruled out since at the temperatures demonstrated for these rocks, the different members so close in composition would be completely miscible.

Diffusion of molecules and ions can take place under the influence of gravity, a chemical gradient and a temperature gradient according to the Soret principle. Bowen (1921) has shown conclusively that such diffusion can be of no practical value in the differentiation of an individual magma. Molecular diffusion as a means of producing rocks of contrasting composition is considered reasonable, but such differentiation probably falls more within metasomatic field than that of magmatism.

In conclusion, it does not seem proabable that

the rocks of the Bauchi Batholith could have attained

their varying compositions by magmatic differentiation.

If the rocks had any magmatic past, they could

possibly have been produced by composite magma.

This is highly hypothetical, but certain features of

the rocks favour it; the rapidity of gradation, the

contrasting colour of the Biotite-Hornblende Granite

and the Fayalite-Quartz Monzonite and the occasional

independent occurrences of Quartz-Diorite and Biotite-

Hornblende Granite in the field.   The essential

problem in this is in accounting for the source or

sources of the different magmas and the mechanism of

their emplacement.

The Space Problem.

The large dimensions of the Bauchi Batholith

have been described earlier.   As an intruded mass,

the space problem for a magma of such huge dimensions

is formidable; - magmatic stoping (Daly 1933) notwith-

standing.   This problem disappears only if the magma

is considered palingenetic.

Some Petrolgraphic Features against a Magmatic Origin.

Most of the plagioclase showed strain effects

characterised by bending of the lamellae and
corresponding wavy extinction. Such strain effects
are not exhibited by the microcline and some grains
of plagioclase. Presumably the rock was solid enough
to be deformed before the introduction of some later
generation of plagioclase and all of the microcline.
This could however be explained as due to deformation
of early crystals in a partly crystalline magma.
This is unlikely from the occurrence of the microcline
as phenocryst-like crystals. So far we have
considered the rocks of Bauchi Batholith, the
migmatitic rocks can now be examined. Bain (1926)
showed that the boundary between the Fine-Grained
Biotite Granite (Fine-Grained Feldspathic Older
Granite -- Bain 1926), and the Biotite Gneisses
(Biotite Granite and Gneisses -- Bain 1926) is
gradational or inderterminable, and yet he recognised
three distinct intrusions within them. The same
gradation is found by Falconer (1911) and by the
present writer. The contrasting aspect of the two
rocks is the presence in one of numerous medium sized *microcline*
crystals and their absence in the other, features that
can hardly be attributed to magmatic differentiation.

In conclusion, if the Bauchi rocks are of magmatic

origin, then the rocks, as far as they are known, do not bear any/unequivocal evidence of this.

Some Evidence of a Metasomatic Origin.

That a metasomatic transformation can result in igneous looking rocks of batholithic dimensions has been shown by the work of many geologists for example, Termier, Lacroix, Sederholm, Holmes, Read, Eskola and Reynolds to cite a very few. Most adherents of magmatic theory conceed that such phenomena commonly termed granitization, can take place to a limited extent around an intrusive mass. Such admission of small scale granitization also implies its possibility on a large and intensified scale. Metamorphic transformation of rocks into varieties of igneous character may be accepted as avalid theory in petrogenesis and for the Bauchi rocks in particular it is a probability.

The geological map of Bauchi, (Map B) shows that the Fayalite-Quartz Monzonite forms the core in a plutonic series arranged in an aureole. Such a petrological pattern is typical of granitization as demonstrated in the several writings of Read, Reynolds, Backlund and other authors. The writer thinks it

probable that a granitic rock mass surrounded by a
zone of migmatization has been made in place as
suggested by Read (1940) more especially if the
contrary cannot be demonstrated. This spatial
relationship is, at least a corroborative evidence of
metamorphic origin.

The contact of the Bauchi Batholith is rather
indefinite. It is rarely seen, but where exposed it
is characterised by development of irregular migmatites.
In few localities it is sharp but without a chilled
margin. In some places there is complete gradation
from one type to the other. Such apparently intrusive
contact features are better explained by localised
mobilization. The Biotite-Hornblende Granite of the
Bauchi Batholith has a lineation structure (from the
linear arrangement of its large microcline feldspars),
which is invariably concordant with that in the Biotite
Granite. (Map B) Some specimens (ME 101, ME 208)
showed that this lineation is present in the Fayalite-
Quartz Monzonite and the Quartz-Diorite as well. The
conclusion seems justifiable that this lineation
structure might be inherited from some previous rock.

The study of myrmekite, perthite and pseudo-
cataclastic structure in the rocks of Bauchi suggested

the probability that the microcline of the rocks is of metasomatic replacement origin (Chaper III).

The microcline crystals look somewhat euhedral and uniformly distributed when viewed casually in ordinary handspecimen or over a wide area in the field, but a stained specimen (Plates 19 and 21) showed that these are crystalloblastic and irregularly distributed. Such textures have been described by King (1943) and Reynold (1943, 1946) and, according to King (1943), by Spurr and Garney (1908) and Anderson (1934) as evidence of a replacement origin for the microcline.

In the angular blocks of the agmatites, large microcline porphyroblasts in all details similar to those of the Bauchi granites are often developed and obviously formed in the solid state. A dykelike body of cataclastic rock just north of Tiruin village, demonstrates a similar case of microclinization (Plate 41, fig. A): After strong cataclastic deformation the rock, a fine grained Biotite Gneiss, has developed large microcline porphyroblasts simply twinned according to the Carlsbad law, some of the porphyro-blasts are about 2 inches by 1 inch and many are set right across the deformation S plane (Plate 41, fig. B). Under the microscope the introduction of the microcline

after deformation is further confirmed. It is thus quite clear that these large microcline crystals are developed in solid rock, being so strikingly undeformed and frequently lying across the shear planes. These porphyroblasts are very similar to the microcline of the Bauchi "granites" showing similar myrmekite and perthite structure.

In the Biotite Granite patches are frequently found where these large porphyroblasts have been sufficiently developed so as to look like the Biotite-Hornblende Granites (Fig. 8) and all gradations are to be found. It is significant that at such localities there is often evidence of some previous deformation (where diffusion, permeation or recrystal-lization are to be expected to be greatest. It is also quite evident that in most cases these microcline porphyroblasts have not participated in the deformation.

Examination under the microscope shows that in all the above cases the microcline porphyroblasts are crystalloblastic. Thus all around the rocks of Bauchi Batholith, are developed, even if only sparsely, microcline porphyroblasts exactly similar to those found in the rocks of the batholith and producing rocks that are hardly distinguishable from the

batholithic rocks. Similar evidence for replacement origin for the microcline of batholithic rocks has been cited by Read (1940) and Perrin (1956).

All over the Pre-Cambrian of Nigeria, Older Granite rocks with large microcline porphyroblasts are described by Falconer (1911, 1921), King and deSwardt (1949), deSwardt (1953), Mackay et al (1949) and others. Their descriptions could be used word for word for the rocks of the Bauchi batholith. The writer has seen the rocks of the Ilesha district described by deSwardt (1953) and some granites near Ilorin close to those described by King and deSwardt (1949), these rocks are in no way different from those of the Bauchi Batholith. The granites of Ilesha and Ilorin are stated by these authors to be formed by microclinisation.

Some of the microcline granites from Sierra Leone, described by Marmo (1955) and from Uganda by King (1943) from Portugal by Schemmerhorn (1956) seem to be in no way different from the rocks of the Bauchi Batholith. According to Marmo (1956) such potassic rocks are widespread in the Pre-Cambrian of Finland. Rocks characterised by extreme coarseness due to large porphyroblasts of microcline perthite

are probably very widespread in the African Pre-
Cambrian, and everywhere it is evident from the work
of various authors that the evidence points to
metamorphic transformation in place which is essentially
a microclinization process.

Turning to the migmatitic series, the Biotite
Granite as described earlier is extremely irregular
in character, with great variation in colour, mineral
content and texture, even within a few yards. The
common occurrence of ghost relics of schist and
schlieren, (represented by biotitic patches) puts
these gneissose granites within the nebulitic granite
of Sederholm· (1926) and explains the irregularity of
the character of this rock. This explains the mystery
of the absence in the Bauchi district of schist and
quartzite which according to Falconer (1911), are
abundant in the surrounding provinces.

It could be argued that such variation could be
attributed to varying degree of assimilation by the
granitic magma (Bain 1926), but assimilation of so
much schist and granulite by a granitic magma
presents a serious energy problem, except if the
magma be derived in situ by palingenesis.

Generally all the "granites" of Bauchi district

show great variation and irregularity in the
distribution and development of the microcline
crystals which can be noticed even in hand specimen
and which is believed to be consistent only with a
metasomatic process.

If a metamorphic origin by transformation in
place is assumed many of the problems facing a
magmatic origin could be solved. The space problem
is reduced to accounting for the loss of only some
ions (i.e. Fe, Mg.), the texture of the rock
becomes easier to explain by microclinization, and
the problem of generating such magma is reduced to
finding the source of the microlinising "ichor"
(Sederholm 1926).

Much of the evidence cited in support of a
metasomatic origin is not entirely unequivocal.
Just as many lines of evidence pointing to magmatic
origin can be equally explained under certain
circumstances by metamorphism, so could many of
these lines of evidence pointing to metasomatic
origin be explained by magmatism under certain
conditions.

The general plutonic setting together with
other field and petrographic evidence discussed above

leads the writer to conclude that metasomatism has played a large part in the evolution of the Bauchi rocks.

However, the Quartz-Diorite and the Fayalite-Quartz Monzonite have some very disturbing features; the distinguishing colour of their feldspars and quartz and their general petrography are strikingly igneous, while the microcline porphyroblasts with continuous lineation through all the rocks and the gradational contacts from the Quartz-Diorite through to the Biotite Gneiss suggest some common history. This could probably be due to all the rocks having metasomatic origin, with these two rocks modified by some near igneous conditions not shared by the other rocks.

The important problems facing a hypothesis of metamorphic origin for Bauchi rocks are; the source of the materials for microclinization, the mechanism by which transformation is effected, the source of energy required to drive the necessary reaction and the disposal of surplus material. It will be shown in the next chapter that these problems can be adequately met.

CHAPTER V. THE GENESIS OF THE BAUCHI ROCKS.

The Archaean Metasediments.

The schists and quartzites which are abundant in the provinces around the Bauchi district were attributed to dynamic metamorphism of an ancient sedimentary series by Falconer (1911). They are represented in the Bauchi district by granulitic relic rocks which occurs as small patches throughout the migmatites. Bain (1926) believed these granulites to be product of dynamic, and to a less extent thermal metamorphism.

The calcsilicate rocks are probably not all derived from limestone but from some basic dykes. Many of them contain enough diopside and garnet to be called calcsilicate rocks, but in some plagioclase feldspar is abundant, garnet is absent and the general texture is granulitic; then, the rocks may be described as elacic pyroxene granulite (ME 237).

Migmatization in the Bauchi District.

The infrequent occurrence of the schists and quartzites around Bauchi, referred to by Falconer (1911) is the direct results of intense migmatization

producing biotite gneisses, lit-par-lit gneiss, agmatite gneiss, and mixed gneisses and pegmatite dykes and ultimately granites.

The term migmatite was first proposed by Sederholm (1907) and according to him (1928) they are hybrid rocks originated by mixture of older rocks and a later erupted granitic magma and he has emphasized the intrusive character of the later rock and designated them "arterite". Holmquist (Eskola 1932) on the other hand regarded this later rock as of metamorphic segregation, exuded from the surrounding rock, designating them "venites." A non-genetic term for this injected or segregated portion of a migmatite is "phlebite" (Barth 1951 p. 364) and the older portion of the rock may be called paleosome (Barth 1951 p. 365).

The phlebites in the Bauchi Migmatites could not have been injected foreign granite magma. They constitute about half of the area of the migmalite and the injection of so much granitic material as thin leaves poses a more serious space problem than that of granitic mass of comparable size since stoping cannot be involved. Quite often a narrow phlebite only about one centimetre broad could be

traced over several hundreds of centimetre. In
agreement with the observation of Currier (1947) and
other authors there is no discernible squeezing aside
of the paleosome bands of granulite in the lit-par-lit
gneiss. In the agmatitic gneiss, the biotite gneiss
has been dissected into numerous angular blocks as in
the case of the agmatites described by Hsing-Yuan-Ma
(1948) from the Shetlands. The angular blocks retain
their regional orientation and are not sharply
demarcated from the phlebites.

The writer therefore considers injection of
granitic magma as suggested by Sederholm quite
unlikely. On the other hand, it is considered
improbable that these are simple cases of metamorphic
segregation as proposed by Holmquist (Eskola 1932).
The segregation of so much quartz and microcline
would leave a residula rock quite different from the
original granulite. From thin section of the gneiss
in which the phlebites are closely spaced, one can
discern distinct alternating bands of granulite and
phlebite and the general impression is one of a mixed
rock. The granulite bands appear to be impregnated
with microcline andquartz and not secreting these
minerals. The phlebite could only have been

introduced by metasomatic replacement, the granulite
absorbing potash and silica as it were from a
solution like a "blotting paper" (Barth 1933), in
exchange for surplus material from its own components.

The various migmatitic gneisses in the Bauchi
district differ from one another only in the varying
degree of development and arrangement of the phlebites.
In the Lit-par-lit Gneiss, the phlebites and the bands
of granulite alternating with it are relatively broad
whereas in the Biotite Gneiss there is intimate and
closely spaced inter-leaving of the granulite with
the phlebites. In much of the Biotite Gneiss, there
are only a faint trail of biotite flakes remaining
from the original granulite bands.

The Agmatitic Gneiss on the other hand is of
blocks of Biotite Gneiss, in which the phlebites are
irregularly introduced as veins, veinlets and sporadic
microcline porphyroblasts. The Biotite Gneiss
dissected by dykes which are relatively wide and
frequently are pegmatitic. In the Biotite Gneiss,
some of the phlebites are seen to have branched off
from these large dykes, which may be called
metatectite (Barth 1951, p. 365), and are therefore
genetically related. In the Mixed Gneisses and

pegmatites, the metatectites are arranged parallel to each other and concordant with the gneisses. The metatectites in the above two cases consist of granitic and pegmatitic dykes and may be regarded as broad phlebites. Their genesis are discussed later.

Granitization.

"Granitization is broadly defined as a process by which rock formations have been changed into rocks of granitic composition and texture without passing through a magmatic stage". (Currier 1947). It almost always involves the introduction of K-Al-Si and removal of Ca-Fe-Mg (Eskola 1948), at least at the early stage. MacGregor (1938) claimed that the ultimate product of granitization is quartz diorite.

Granitization in the Bauchi district fits more to the broad definition but it is generally a process of microclinization. The granites were formed from the gneiss dominantly in this way. The Biotite Granite which cannot be demarcated from the Biotite Gneiss is distinguished only by numerous small porphyroblasts. Though they tend to grow "with their two, longer axes within the S plane" (Harry 1951), the general tendency is to subdue the foliation, by

decrease of biotite, making the rock more granitic
looking. The microcline first appears as a number of
small intergranular grains that are optically continuous
(Plate 42 fig. A) and as these grow towards one another
and coalesce they form bigger porphyroblastic grains
with inclusions of other minerals (Plate 42 fig. B).

As the microclinization is intensified, presumably
directed by the differential distributions of free
energy (Perrin 1956), still larger plates of micro-
cline up to 3cm. long are formed. Biotite appears to
be partially altered to hornblende, contributing
potassium to the growing crystals. The resulting
rock is the Biotite-Hornblende Granite. Increasing
amount of pore fluid could have contributed to the
development of these large porphyroblasts. Petrographic
inspections of the plagioclase show that the Biotite-
Hornblende Granite had been slightly sheared previous
to the introduction of microcline. This is in agreement
with the experience of Marmo (1955, 1956) who has
observed similar relationships between zones of
shearing and shattering and the large potash
porphyroblasts in the synkinematic granites of Sierra
Leone. Presumably the shearing, apart from
facilitating the movement of material, has raised

the free energy level thus favouring the crystal-
lization of large microcline porphyroblasts.

The course of granitization of the gneisses
through the Biotite-Granite towards the Biotite-
Hornblende Granite is reflected in size and proportion
of microcline and the consequent textural changes;
this was also the experience of King and De Swardt
(1949).

The Nature and Origin of Migmatizing and Granitizing Fluid.

Potash metasomatism by which sedimentary and
metamorphic formations become granitic is known
world wide in the Archaean. (Eskola 1933) It has been
described from various parts of the world. (Querke
1927, King 1943, Marmo 1945, 1955 and Schedmerhorn 1956,
to mention only a few). The abundance of such potash
metasomatism in the earliest rocks in the deeply
eroded zones of the earth is significant, suggesting
that it is essentially a plutonic process.

The source and nature of the emanation responsible
for this potash metasomatism or granitization has
puzzled petrologists for many years, as revealed in
the excellent reviews of literature of granites by Holmes
(1945): In 1824 Ami Bone attributed veins and

disseminated crystals to heat and gases coming from
the earth's interior.   Devile, seventeen years later,
introduces the idea of mineralizing agents.   French
geologists were amongst the earliest to be convinced
of the process of feldspathisation and granitization.
Following other geologists before him Virlet d'Aoust
expressed the idea that igneous materials have soaked
into sedimentary and metamorphic rocks and so altered
them to granites; and he designated the process
"imbitition" which he later spoke of as
"granitification".

Michel Levy and Lacroix towards the end of the
19th century proposed a granite magma as the agent
effecting granitization designating it "Corteges
d'emanations" (Currier 1947).   This was later termed
"Colonnes Fitrantes" by Fermier (Holmes 1945) who
explained that these highly energized emanations only
became granite after combining with the existing
rocks, and that they originated from the depth.

From these emerge the present-day ideas on the
problem, among the leading views are those of Sederholm,
Eskola, Backlund and Reynolds.

Both Sederholm and Eskola, appear to favour a
magmatic source for the granitizing material. Sederholm
(1926)

(1926) proposed the term "Ichor" to denote a magma
diluted with water and containing other mineralizers
percolating through older rocks like an oil spot and
dissolving some of their minerals and replacing them
with others. The ichor is derived by melting or
refusion of the lower part of granitic crust, a process
which he termed anatexis (Sederholm 1928 and 1933).
Eskola's ideas are allied to those of Sederholm. He
considered granitization and migmatization to be due
to granitic magma produced by squeezing out the lowest
melting materials of silicate rocks during orogenesis
(Eskola 1932 a, b and c, 1933). The granite magma
permeates the rocks impregnating them with granite
minerals and as a rule rising upwards.

In respect of the rocks of the Bauchi district
such granitic magma may be regarded as being
essentially a solution of alkali feldspar and quartz.
As this solution rises upwards permeating the granulite
with its granitic materials, as suggested by Eskola,
it would have to receive the surplus femic material,
as Sederholm also realised (Sederholm 1926). As the
solution "as a rule " (Eskola 1933) continue to rise
upward it will have eventually to dispose of the
basic material with which it is becoming saturated

into the over-lying rocks. There is no evidence for
this. Such a solution could hardly be ordinary
granitic magma, for it should, presumably, possess
superheat and be highly attenuated to be capable of
such close impregnation of the granulite; further it
should possess an efficient means of disposing of the
basic material it has "dissolved" (Sederholm 1926)
without itself losing its power of continuous
impregnating of the metamorphic rocks with alkali
feldspar. So simple a granitic magma as described by
Sederholm and Eskola could hardly have been operative
in Bauchi.

Reynolds, Backlund and Bugge on the other hand
believe that granitization is essentially a process of
ionic diffusion in the solid state. According to
Reynolds 1947, the transformed rocks, in general,
undergo a change "far intimately woven in the rock
to be attributed to fluids", and the process of
transformation are dependent on some form of physico-
chemical control in solid state. Emanations are thus
a "migration of ions within solids by way of structural
faults, deformation, crystal discontinuities and by
means of potential difference of lattice energies".
(Backlund 1946) Ionic diffusion in this way has

been evoked by Bugge (1945), Marmo (1955), Perrin
(1956) and several others to explain large bodies of
granitic rocks.

One of the strongest experimental information in
support of this process is that published by Adams
(1930). Two magnesite bricks of different compositions
were heated in an oven and one had softened and bent
over to touch the other along a knife edge through
which diffusion had taken place with the result shown
diagramatically (Fig. 14) by Read (1948). Even in
this there is considerable doubt if the diffusion
has not been in a fluid phase. (Read 1948) Experi-
mental work has shown that diffusion in solid state
do take place but it has not been sufficiently
encouraging for the application of such process to
extensive migmatization and granitization (Walton
1955) such as that illustrated by the Bauchi rocks;
for as pointed out by many authors, dry ionic diffusion
is too painfully slow to effect such large scale
metasomatism.

On the other hand, dry ionic diffusion as
demonstrated by Bugge (1945) might have played an
important part in the metasomatic reconstitution of
individual minerals; as for example in the

pseudomorphic development of hornblende on biotite
or pyroxene, but the long distance transportation of
material or even of exchange of ions between adjacent
minerals seems more probably to be through a fluid
medium. In any case, the formation of the pegmatitic
and granitic dykes in agmatite, intimately connected
in genesis with the impregnation of the surrounding
schists and gneisses with microcline and quartz as
seen in the Bauchi district are obviously difficult
to relate to dry ionic diffusion of the element. The
rock pores must constantly be filled with fluid
whether in gaseous or liquid state, for the fluid
pressure is constantly not far from the load pressure
(Fyfe and others, 1958p. 181) ensuring the constant
presence of this pore fluid. Exchange of material
through this pore fluid is more probable.

Falling between the various views expressed
above, many petrologists in discussions on migma-
tization and granitization, commonly refer to
emanations, solutions and gases associated with
hypothetical magmas.

It is doubtful if the process of large scale
plutonic granitization and migmatization can be
attributed to emanating fluids originating from a

magma and moving upwards. It has been observed by
Lacroix as far back as fifty years ago that the
granitizing agent only produces granite after combining
with the older rocks; and as commonly accepted, the
process involves dominantly the introduction of
potash feldspar and silica: In many instances it is
quite evident that only potash has been introduced,
while in others a limited amount of Al and Si might
have been introduced as well. Broadly conceived the
process as stated earlier is one of introduction of
K-Al-Si and removal of Ca-Fe-Mg. If the agent were
simply a fluid emanation, it would itself get
progressively cooler and more altered in composition
towards a basic one, and it can hardly be expected to
effect so deep and extensive an impregnation of the
older rocks with microcline and quartz as is observed
in the Bauchi district. Bott (1956) has demonstrated
from geophysical evidence that such an hypotheses
involving upward and sideways disposal of basic
surplus material is incompatible with the structure
of granite bodies. Thus this solution, gases or
emanations like Eskola's granitic magma as a rule
ever moving upward must necessarily conflict with
Bott's geophysical evidence.

Read (1944, 1946, 1948) classified rocks as
Neptunic (the sedimentary rocks, mostly marine),
volcanic (the magmatic igneous rocks, dominantly
effusive and basic) and Plutonic (the metamorphic,
migmatic and granitic rocks) and "saw the granite
problem as one closely tied up with migmatization
and metamorphism - as a plutonic problem."

The evidence furnished by the Bauchi rocks is
more in support of Read's theory of granite genesis.
The spatial arrangements of the rocks could be best
explained as of a plutonic series. Therefore, the
introduction of potash feldspar and quartz and removal
of femic components must have been by some plutonic
process. Since the transportation of components is
presumably not by dry diffusion, it must be through
the medium of pore fluid irrespective of the physical
state of this fluid.

The writer considers that the hypothesis of
Korzhinsky (1936, p. 58) offers a hopeful solution to
the problem:

> "Let us conceive the mechanism of metasoma-
> tosis as follows: along a network of fissures
> through rock flow solutions. But the rock does
> not react with these flowing solutions, it reacts
> with an immobile solution permeating the sub-
> microscopical pores of the rock and serving as
> an intermediary between the whole rock mass and

the flowing solutions. The introduction or
leaching of rock components are affected by
diffusion through this immobile subcapillary
medium which we shall name "solution" irrespec-
of its liquid or gaseous state."

It is necessary to distinguish two cases -

"The diffusion of certain components may
proceed so rapidly that the concentration of
these components in subcapillar solutions and
in solutions flowing through fissures may remain
all the time at the same level, independently of
the course of the reaction between the solution of
and the rock; in such a case the reaction proceed
as if the rock reacted directly with the flowing
solution. Such components will be called the
"ideally mobile". Slowly diffusing components
cannot maintain their concentration in the
stationary solution at the same level as that of
the concentration of the flowing solution. This
concentration will vary depending on the
absorption or loss of components by the rocks and
the difference between this concentration and
that of local solution saturated by the rock
mineral will be infinitely small. Such component
may be called inert."

Korzhinsky then went on to make two propositions:

"Proposition 1. Let the mineral aggregates
be in chemical equilibrium with the solution at
arbitrary temperature and pressure. Then:

1) The maximum number of minerals is equal
to the number of inert components (and does not
depend on the number of ideally mobile components)

2) The mineral composition is fully
determined by the quantitative correlation of
inert components.

Proposition 2. Let the mineral aggregate
remain constantly in chemical equilibrium with
the solution at arbitrary temperature and
pressure.

1) If the existence of several mineral
association with the different content of the
mobile component is possible at a given
correlation of inert component, then with an
unlimited increase (or decrease) of the
concentration of this mobile component in the
solution successive formation of all these
mineral associations without exception will be
observed to occur, these associations replacing
one another with the increasing (or decreasing)
content of the mobile component in strict order.

2) These substitution reactions will occur
at singular concentrations of the solution. At
intermediate concentrations there may occur only
enrichment (or impoverishment) with the mobile
component of the minerals of variable composition."

Thus the migration of elements during metamorphism

or metasomatism could be through the mobile solution

and their reaction with older rock minerals to form

new mineral may then be through the immobile solution.

At a given temperature and pressure K_2O is relatively

"ideally mobile" and SiO_2 and Al_2O_3 are relatively

"immobile". (Korzhinsky 1936, pg. 60). During

microclinization the concentration of K_2O in both the

mobile and immobile solutions should be constantly

maintained and that of SiO_2 and Al_2O_3 less so. These

last two components, however, are largely supplied by

the older rocks being replaced. (The chemical

composition of the Bauchi rocks show progressively

less silica with advanced granitization while the

alumina show little variation). In any case their
mobility would also have been influenced by chemical
potential and other physico-chemical law, for as
pointed out by Korzhinsky (1936, p. 60) the greater
the intensity of metasomatism the greater the number
of components that are mobile.

During granitization, the resulting rock depends
on the replaced rock for the bulk of its inert
components, i.e. SiO_2 and Al_2O_3 but not for the mobile
component i.e. K_2O. Thus rocks excessively poor in
one of SiO_2, Al_2O_3 or both (as for example quartzite
and limestone) are relatively resistant to granitization
(Reynolds 1948, Eskola 1948). Thus the process of
granitization is justifiably described as one of
potassium enrichment.

The Source of Potash.

If the process is viewed, as the writer believes
it should, as belonging to plutonic metamorphism, the
source of potash becomes easier to understand. The
mineral assemblage in the amphibolite facies is
characterised by the prevalence of amphiboles and
mica that of granulite facies among other minerals
is characterised by perthite potassium feldspar.

Potassium bearing minerals are not represented in the eclogite facies, and the potassic ion must be relatively unstable at the greater depth.

Viewed in terms of structural layering of the earth, Geophysical evidence points to the stratification being according to density and basicity. This stratified condition of the earth must have been attained early in its history even if imperfectly. If the ideal state had been attained, the distribution of the principle cations of silicate rocks can be hopthetically represented on a diagram (Fig. 15). This ideal stratified condition is constnatly upset by the extrusion of basic magma from depth which on weathering is incorporated in sedimentary rocks of large geosynclines, later to form metamorphic series more basic than the granites they overlie. This relatively basic mantle of metamorphic rocks is now demonstrated by geophysical evidence (Bott, Personal Communication). In terms of the diagram (Fig. 15) the overlying metamorphites may be considered structurally unstable and the femic components would be displaced downwards by potash when the correct thermodynamic condition was reached.

The down warping of the crust during orogenic

movement or during sedimentation in large geosynclines could initiate upward migration of potash. The metamorphic aspect of this process can be appreciated by consideration of the metamorphic facies: with depression into deeper part of the earth, the amphibolite passes to granulite facies and the granulite towards eclogite with consequent migration of potash.

In the Bauchi rocks in the transition from granulite to Biotite Granite, most of the early potash feldspar is formed at the expense of biotite, chemically only about a quarter of the potash in the granite came from outside, (Fig. 18) and this appears to have come from the zone of transition to diorite. Consequently when viewed broadly, the process as possibly operative in Bauchi district is one of reorganization under plutonic metamorphism as long maintained by Read.

The view expressed above is summarised by Walton (1955): "The Alkalis are less capable of entering stable solid phases at depth in the earth's crust than ferromagnesian elements, and a potential exists for their relative movement upward.

The Source of the Driving Energy.

Several sources of heat for driving the process ofmetasomatism have been suggested. Most invoked is the geothermal heat, Eskola (1933) Sederholm (1928) and many others. Some authors have suggested radioactive heat, among them, Bugge (1945) who pointed to the possibility of heat emitted by disintegration of K40 to Ca40 especially in the first milliard years of the earth's history.

Backlund (1946) suggested that much energy is not required. According to him: "minor influx of Na and Si associated with suitable thermodysnamic condition seems to be all that is necessary to start a whole chain reaction". This view is more directly expressed by Perrin (1956), that granitization governed by the tendency to lower the level of free energy necessarily involves heat emission, therefore granitization is an exothermic metasomatism.

Radioactivity as a source of energy in migmatization and granitization is highly hypothetical. The spatial arrangement of the Bauchi rocks, at any rate, does not appear to favour this suggestion. On the other hand, the view that granitization is exothermic is doubtful; so much heat would have been

generated in the Bauchi area that the rock would
eventually have been melted. Conceived as a metamorphic
process, the source of heat energy could be essentially
geothermal. The spatial arrangement of the Bauchi
rocks probably corresponds with increasing temperature
inwards; but such need not necessarily be due to a
magmatic effect, for the most depressed zone should
have likely reached higher temperauture.

The Disposal of Ca-Fe-Mg in Granitization.

Reynolds (1947a) demonstrated the hypothesis of
the "basic front" by which he showed that the Ca-Fe-Mg
released during granitization was being fixed along
the fronts of granitization. The amount of basic
materials so fixed is, however, comparatively
insignificant when compared with the vast amounts of
Ca-Fe-Mg released during granitization of some rocks.
As stated earlier, Bott (1956) had shown that such
sideways or upward migration of the basic material is
in conflict with the available geophysical evidence.

In the Bauchi area the writer has no evidence
which could lead him to believe that there had been
any substantial migration of basic components outwards
at the front of migmatization though this is not

disclaimed. Presumably these components have been exchanged for potash; as such it is quite likely that a little quantity has been fixed in the surrounding rock but most have probably migrated down in the mobile solution to the depth from which the potash is originating. In respect of the minerals forming at such depth, CaO, MgO, FeO and Fe_2O_3 are in term of Korzhinsky's hypotheses the mobile components. The writer is thus in agreement with Perrin (1956) that these components "mostly have moved down". This view is in accord witht the geophysical evidence of Boôt (1956). Just as a potential exists for the upward migration of alkalis from the depth where they are unstable (Walton 1955), there must be some such potential for the downward migration of the femic elements even though this has not been as convincingly substantiated as that of the upward movement of the alkali.

The Origin of Pegmatites and Metatectites.

A large number of pegmatite dykes are to be found throughout the migmatite area. They are particularly concentrated in the north of the area where they form nearly half of the total exposed rock surface. In

the agmatitic gneiss, the granitic and pegmatite
metaectite are also of as much surface area as the
gneiss blocks. Despite this, no squeezing or
crumpling is to be observed in the surrounding rocks.
This is especially striking in the agmatites where the
blocks retain their orientation as demonstrated by
the continuity of lineation. The contact is usually
indefinite and it is gradation into the gneisses which
are themselves impregnated with quartz and microcline.

Eskola (1932) regarded the metatectites as being
lef/tbehind after granitic magma formed by differential
fusion had been squeezed out along these passages during
orogenesis. Generally this suite of granitic and
pegmatite dykes appear to overlie and surround the
large granitic bodies, not underlie them as implied by
Eskola's hypothesis. These dykes are obviously not
injected bodies if only for the great overall volume
involved. They most probably have been formed by
peaceful reconstitution or replacement of the gneisses.
Simple magmatic soaking, as suggested by Kemp (1924)
will not satisfactorily explain the structure of all
pegmatites. As pointed out by Hess (1925) a long
continued flow of solution must be assumed and this
must have been concentrated along certain zones.

The dykes might have been formed by the same processes of metasomatism as was discussed earlier under granitization, and based on Korzhinsky's hypotheses and Hess's long-continued-flowing solution might be identical with the mobile solution of Korzhinsky's (1956). The concentration of metasomatism along certain channels to form dyke bodies may be due to the effect of distribution of mechanical pressure or free energy on the diffusing components. The process of granitization involving introduction of some K in place of Ca, Fe and Mg could have resulted in some volume increase contrary to the conclusion of Currier (1947). This volume increase might have caused slight doming of the overlying rock, and the distribution of stress in the overlying rocks could have resulted in the creation of numerous zones of low mechanical pressure (Fig. 16) which may not be actual open fissure. Towards such zones, diffusion of components in the solution should tend to be concentrated to form pegmatite and granite dykes and veins including quartz veins. By some such process so much dyke rocks could form without in any way disturbing the surrounding rocks.

The Evolution of the Bauchi Rocks (Summary of Discussion)

Most of Nigeria was probably once covered by
sedimentary rocks which were metamorphosed to schists,
quartzites, amphibolite, and calcsilicates in the
normal cycle of regional metamorphism during the Pre-
Cambrian times.   These are still found over most of the
country where not obscured by Cretaceous sedimentary
rock or completely granitized, as in the Bauchi district.

In the Bauchi district the metasedimentary rocks
appear to have been converted to granulites with
irregular masses of clacsilicate rocks.   From these
granulites, the evolution of the present Bauchi rocks
began with the interstitial development of microcline
and a corresponding decrease in the proportion of
biotite.   Most of the early components for the micro-
cline are taken from the biotite and the downward
migration of the basic material must have started very
early.   This process, if it could be called granitiza-
tion, was controlled by the planes of schistosity and
differential rates of development lead to the develop-
ment of the lit-par-lit gneiss.   As the process
advanced, the intervening bands of granulite also
succumbed to granitization and only short parallel
streaks of biotite and few schlieren were left to

indicate their former presence. Thus the biotite gneiss was evolved.

From here on, the course of granitization is reflected in the field mainly by textural changes. There is a marked and progressive, thought not entirely gradual, disappearance of the original fine grained granular texture and the emergence of medium to coarse porphyroblastic aggregates. King and de Swardt (1949) remarked on a similar trend of development in the Osi area of Nigeria. Although themicrocline porphyroblasts tend to grow with their longer axes in the plane of foliation of the original rock, the general effect of their development is to obliterate the gneissose appearance and alter the rock progressively towards one of granitic aspect.

These transformation are believed to fall within the normal cycle of regional metamorphism and to have been under the temperature and pressure condition equivalent to the amphibolite-granulite facies. The intensity appears to be normally a function of depth (fig. 17) though subject to many variables whose influences are not well known, among them: extraneous heat from consolidating abyssal magma, fluid emanation affecting change of temperature and or fluid pressure,

stress and the bulk composition of the metamorphites. (Fyfe and others 1958)

Acting seperately or in concert, these would tend to make the intensity of granitization complexly varied, at a given plane in a plutonic series. Thus in Bauchi one is still able to observe the various stages of development from Lit-par-lit Gneiss to the Biotite-Hornblende Granite despite the deep erosion.

The principal stages in the development represented in the diagram (Fig. 17) form aureoles around the core of Quartz-Diorite (Map B) from where, it would appear to emanate heat and solutions.

The mineralogical changes (Fig 18) show that the entire process is a metamorphic redistribution of rock components in an effort to reach a state of equilibrium under plutonic conditions.

CHAPTER VI.   THE QUARTZ-DIORITE AND THE FAYALITE

QUARTZ MONZONITE

The Similarity of the Quartz-Diorite to Charnockite.

The Quartz-Diorite which has been described earlier, (p43-46) is a member of a series of charnockitic rock which are now known to be fairly widespread in the Pre-Cambrian rocks in Africa.   In the Bauchi area it comprises a small part of the batholith.

The term "charnockite" was proposed by Holland (1900) for an Indian rock, composed of quartz, microcline, hypersthene and iron ore; "a rock which would have been ordinarily called hypersthene granite", (Pichamuthu 1953).   It is now customary to classify hypersthene bearing rocks of plutonic association with greenish to bluish brown colour as acid charnockite (about the composition of a granite), intermediate charnockite (about Quartz diorite to diorite in composition, basic charnockite (of basic composition) and those of ultrabasic composition as ultrabasic charnockite.

In addition, a number of special varieties are described in the literature though not all of these

have been generally accepted; among these varieties
are Arendalite described by Bugge (1943) as a series of rocks
of "noritic charnockite" character, and Enderbite
described by Tilley (1936) as a type with distinctly
low K_2O and high Cao and SiO_2 and composed "of anti-
perthite (53%), quartz (42.5%), hypersthene (3%) and
magnetite (1%)".

The specimens from Bauchi, though of fairly
variable composition, fall into the intermediate
charnockitic norite division except for a few
specimens (i.e. ME102) which correspond more with
the acid division. The similarity may be appreciated
by a comparison of the Bauchi rocks (Table 8) and
some intermediate Charnockites from India (Table 9).

Comparison of the Charnockite Rocks from Bauchi with Intermediate Charnockite from India.

The Bauchi Quartz-Diorite rocks generally have
less free quartz but slightly more potash feldspar
and less plagioclase than the Indian intermediate
charnockites. Hypersthene is about equally abundant
in both groups but the Bauchi rocks have a much higher
percentage of hornblende and biotite. Ore and apatite
are present in approximately the same proportions but

TABLE 8

The Modal Compositions of Quartz-Diorite from the Bauchi District.

	1	2	3	4	5	6	7	8
Quartz	0.9	1.0	2.1	3.4	3.4	3.6	4.9	8.6
Myrmekite	0.6	0.0	0.7	0.0	0.3	0.0	0.0	0.8
Microperthite	11.1	8.7	12.2	0.0	11.6	16.1	0.9	31.9
Plagioclase	57.1	50.1	45.0	45.0	53.3	57.2	39.0	31.6
Ferrohypers-thene	20.3	19.2	25.6	17.6	16.1	8.5	23.9	5.3
Clinopyroxene	2.9	0.5	0.6	14.0	2.1	2.2	10.8	0.0
Hornblende	2.9	12.3	6.2	4.0	8.8	8.0	10.6	11.6
Biotite	0.	2.2	2.1	12.0	0.2	1.2	9.9	9.4
Magnetite Ilmenite	4.1	6.0	4.5	4.4	3.8	2.2	0.3	1.5
Zircon/Apatite	trace	trace	0.9	trace	0.5	0.9	trace	0.5
	99.9	100.0	99.9	100.4	100.1	99.9	100.3	101.2

1. ME113 Central Valley, North Kofar Wombai Hills, Bauchi, N. Nigeria.

2. ME207 South of Tiruin Village, Bauchi.

3. ME224 East of Yelwa Road, S. of Agricultural farm, Bauchi.

4. ME226 Near Gundun Hill. S. of Bauchi Wall.

5. ME208 S.W. side of Kwinin hill. Bauchi.

6. ME209 North end of Kofar Wombai Hill, Bauchi.

7. ME225 S. of Jos Road, Village about 8 miles W. of Bauchi.

8. ME About 100-150 yards W. of Yelwas Bridge, Bauchi.

TABLE 9 *

The Modal Compositions of Some Intermediate Charnockites

from India.

	1	2	3	4	5
Quartz	8.7	5.0	6.1	15.5	4
K. feldspar	7.4	26.2	3.8 }	55.5	4
Plagioclase	61.2	49.7	52.9 }		2
Hornblende	0.1	-	1.4	-	-
Biotite	0.1	-	7.9	-	-
Hypersthene	17.6	8.3	5.5	23.6	18
Augite	-	6.2	13.7	-	15
Garnet	-	-	-	-	-
Ores	4.6	4.4	4.6	5.4	15
Green Spinel	-	-	-	-	-
Apatite	0.3	0.2	1.1	-	1

* From Howie (1955) p. 98 Nos. 18-21 and 27.

1.   Shevaroy Hills, Madras.   Anal. J.H. Scoon.

2.   Intermediate Rock, Tinnevelly district, Anal.
                                    R. A. Howie.

3.   Intermediate Rock, Salem, Madras. Anal. J.H. Scoon.

4.   Intermediate Rock, Shevaroy Hills, Madras. Anal.
                                    H. S. Washinton.

5.   "Norite" St. Thomas Mount, Madras.

but there are small amounts of zircon in Bauchi rocks.

Both the Indian charnockites and the Bauchi dior-itic rocks are generally dark greenish to bluish in hand specimen and the quartz is of greasy brownish green colour, but the Indian rocks have yellowish tinge (Howie, private communication). In section the quartz in the Bauchi rocks is clear but show strong undulatory extinction. Those of the Indian charnoc-kites are of xenomorphic granular texture. Pichamuthu (1953 p. 9) mentioned that the quartz in Indian charnockite, in general, contain dusty or acicular inclusion, but according to Howie (1955 pg. 759) this is only occasionally so. Their plagioclase ranges from oligoclase to andesine and it is frequently antiperthitic. The potash feldspar is invariably perthitic (Pichamuthu 1953, Howie 1955). These characters are observed in the Bauchi rocks, except that the plagioclase is only occasionally antiperthitic. Thin hair-like inclusions like closely spaced dashes were observed in the plagioclase crystals of one specimen (ME226) while the quartz is usually clear. The orthopyroxene in the Bauchi rocks is ferrohypers-thene and the clinopyroxene is ferroaugite, so it appears that the pyroxenes of the Bauchi rocks have a

higher proportion of iron to magnesia than those of Indian charnockite. In one specimen (ME226) the ortho-pyroxene is generally clouded with brownish acicular inclusions which Howie (1958) recorded from Indian rocks. As in the type charnockites, the hornbelnde of the Bauchi rocks is usually pale greenish and pleochroic with X = pale greenish, Y ≠ dark brownish green, Z = brownish green.

Occurrence and Distribution.

Nigeria:- The first note of a rock of charnockitic affinity in Nigeria was made by Falconer (1911) in Toro about 50 miles west of the district at present under study. King and DeSwardt (1949) described a norite from Osi in Ilorin province which is very similar to the Bauchi rocks. Apart from these no other occurrence of charnockite rocks is known in Nigeria, with the excep-tion of the rocks at present under investigation in the Bauchi district. It seems not unlikely that further examples may come to light with increased geological knowledge of the country.

In the Bauchi occurrences, their relationship to the Pre-Cambrian gneisses in which they occur is usually indefinite since the contacts are not directly

observed, but it appears that this must be sharp from the suddenness from which one may pass from outcrops of charnockitic rock to those of the country rocks; but it is doubtful if they have intrusive character for they are usually elongated bodies generally concordant with the foliation of the surrounding gneisses.

Africa:- Charnockites and charnockitic rocks are becoming increasingly known in the Pre-Cambrian areas of Africa. Pichamuthu (1953) gave an impressive list of African charnockites and recently Howie (1958) gave petrographic details of some African occurrences. They tend to have the same indefinite relationship to the surrounding gneisses, but Groves (1935) mentioned some intrusive characters in the charnockites of Uganda.

Others

Pichamuthu (1953) gave a list of world occurrences of charnockite and related rocks which need not be repeated here.

In general charnockites appear to be most abundant in the Pre-Cambrian terrains, thus falling into the Read's (1948) plutonic group of rocks.

The Fayalite Quartz Monzonite

This rock would also be classified as a Charnockite except that hypersthene is generally absent. In many of its other petrological characters it resembles Charnockite, for example; the greenish to yellowish brown colour of the rock, the resinous greenish brown colour of its quartz, microstructure such as perthite and the mineral aggregate texture. In contrast to charnockites proper, this rock has fayalite as its characteristic ferromagnesian mineral. The associated pyroxene is ferrohedenbergite; orthopyroxene is not common but occasionally it may be locally abundant.

The rock is variable in modal composition; this is difficult to determine because of the coarse grain size. From a consideration of the potash feldspar: plagioclase: quartz ratio, the rock normally belongs to the monzonitic series and varies from quartz syenite to adamellite. This variation is rather sporadic and may be observed in hand specimens (Plate 21 fig. B). Thus the rock would ordinarily be described as a Fayalite-Hedenbergite-Quartz-Monzonitic Rock.

The rock has certain distinctive chemical

feature. The chemical peculiarity of fayalite bearing rocks in general was summarised by Tomkeieff (1939 p. 246); accoding to him the average and range of composition, of 10 analyses by Hawkes and 12 by himself, of fayalite bearing rock was as follows:-

SiO_2 ...... 65.20 (56.59 - 75.55)

Na_2O ...... 5.42 (3.21 - 6.59)

K_2O ...... 4.53 (1.59 - 6.63)

FeO (Fe_2O_3) : FeO (Fe_2O_3) + MgO 0.95:1

This, he concluded "shows that fayalite bearing rocks are alkalic and range from intermediate to acid and in the majority of cases are quartz bearing". The composition of the Bauchi fayalite-bearing rock supports this conclusion, but in this rock there is a higher proportion of potash to soda. Most of the British Tertiary rocks containing fayalite have relatively higher potash than soda (Emeleus Oral Communication). The most distinctive chemical aspect of fayalite bearing rocks appear to be the high $FeO:MgO$ ratio. Both the Bauchi rocks and the fayalite bearing rocks of the Younger Granites are characterised in addition by high $FeO:Fe_2O_3$ (Table 10)

In many of the occurrences of fayalite-bearing rocks, hedenbergite is often the typical clinopyroxene

and the colour of the rock is almost invariably green
to greenish brown. Thus the rock has distinguishing
peculiarities quite as bold as and differing from,
those of a charnockite. The rock cannot be described
as a charnockite without transgressing the usual
definition of the type; the descriptive term Fayalite-
Hedenbergite-Quartz Monzonitic rock is more explicit
and will be used although cumbersome and not fully
conveying the special peculiarities of the rock. If
there is any justification for naming rock varieties
however, this rock ought to be a Pseudo-charnockite,
from its close resemblance to the normal charnockite
in all characters except in the presence of fayalite.

Occurrence of Fayalite bearing rocks in Nigeria

Fayalite-bearing granitic rocks are a common
member of the ring intrusion series of the Plateau
Younger Granites. Since Bain described them from
Kudaru in 1934, they have been described, by Mackay
(1949) and more recently most of the occurrences in
the Younger Granite Complex have been described, with
petrographic and chemical details, by Jacobson and
others (1958). Occurrences within the Older Granite
Complex outside Bauchi are not known, but the Older

TABLE 10

CHEMICAL COMPOSITION OF THE FAYALITE ROCKS FROM THE

YOUNGER AND THE OLDER GRANITES.

	1	2	3	4
SiO_2	67. 96	70. 59	68. 65	71. 51
Al_2O_3	14. 77	13. 90	13. 50	12. 91
Fe_2O_3	0. 98	1. 17	0. 93	1. 14
FeO	2. 88	2. 30	3. 97	2. 87
MgO	0. 41	0. 30	0. 55	0. 15
CaO	2. 37	2. 08	2. 14	1. 16
Na_2O	3. 25	3. 30	4. 18	4. 17
K_2O	5. 75	5. 55	4. 85	5. 12
H_2O+	0. 36	0. 33	0. 57	0. 16
H_2O-	0. 16	0. 14	0. 09	n. d.
TiO_2	0. 38	0. 33	0. 54	0. 30
P_2O_5	0. 12	0. 15	0. 17	0. 04
MgO	0. 04	0. 05	0. 10	0. 09
BaO	0. 44	0. 13	—	—
Cl	n. d.	n. d.	0. 03	0. 02
F	n. d.	n. d.	0. 22	0. 09

1. ME 101 Kobi Hill, by water concrete tank, Bauchi.
2. ME 223 Foot of Kofar Wombai Hill by the Slaughter
House, Bauchi.
3. L. 1623 (see Jacobson and others 1958, pg. 20)
3. B. 851 ("   "   "   "   "   ")

Analyses 1 and 2 are by kindness of the Principal, Mineral Resources Division, Oversea Geological Survey, London.

granite areas have not been investigated in any detail so further examples may well appear.

Occurrences of Fayalite-bearing Rocks in the World:-

AFRICA (Outside Nigera)

Howie (1958) mentioned occasional occurrences of fayalite in charnockitic rocks in the Sudan.

AMERICA

Buddington (1952 pg. 58) gave the chemical petrology of a Fayalite-Hedenbergite Granite and a Fayalite Granite pegmatite from the Adirondack complexes and Chapman (1935) described fayalite-bearing syenite from the Percy Ring Dyke Complex of New Hampshire. Murdock and Webb (1940) noted the occurrence of fayalite crystals in litho-physae in rhyolite in California (Inyo County) and, more recently

Palache (1950) described fayalite at Rockport, Massachusetts and mentioned four occurrences of fayalite granite on Cape Ann, near Boston, in nordmarkite xenoliths within a later granite.

AUSTRALIA

Fayalite Gabbro with hedenbergite was
described from Australia by Simpson (1938)

EUROPE

Finland: Savolakti (1956 p. 56) described a greenish
yellow granitic rock with fayalite (5.1%)
from the Ahvenists Massif.

Great Britain: Professor F. H. Stewart (Private
Communication) mentioned several occurrences
of fayalite in the Tertiary acid rocks of
Scotland among them the well known fayalite-
bearing pitchstones from Arran (Tyrell, 1928)

Greenland: Fayalite occur in later basic and acid
rocks of the Skaergaard intrusions.

Iceland: Noe-Nygaard has reported fayalite in liparite
(Professor Campbell, personal communication)
and Hawkes (1924) described fayalite dacite
from the Tertiary Volcanic Series of Eastern
Iceland.

Ireland: Dr Emeleus also mentioned (oral communication)
the occurrence of fayalite in the Porphyritic

Granophyre and Felsite on the Slieve
Gullion ring-complex originally described
by J. E. Richey and H. H. Thomas. (1932)

JAPAN:

Kurio (1940) described the occurrence of
fayalite in some dacites from North Izu and
adjacent areas.

Most of these occurrences of fayalite-bearing
rock will be seen to belong to high level intrusion,
and as mentioned by Professor Campbell (Private
Communication) many of them occur in ring-dyke complexes.
The Bauchi rock with a deep seated plutonic setting is
therefore peculiar.

Petrogenetic Discussion

The spatial position of the charnockitic diorite
and the fayalite-bearing rock in the core of a migma-
titic aureole is such as to suggest them as being the
centre of activity, occupying as it were a position
from which energy and substances emanated to transform
the metamorphites to migmatitic granites. They fit
better into this role conceived as a zone of relative
higher temperature and pressure. To any one seeing
them casually in hand specimen or in section the two

rocks would suggest an origin by direct crystalliza-
tion from a magma, yet they have some very disturbing
features which make one cautious to assign to them such
a genesis. These features have been earlier reviewed.

The dominating feature of these rocks is the
equivocal character of the petrogenetic evidence
furnished by their structure, much of which could
individually, be cited for magmatic or metamorphic
origin. This could be due to the rock having a mixed
origin.

Two possibilities suggest themselves: The diorite
was crystallized from a magma and the Fayalite-Quartz
Monzonite was formed by microclinization of the diorite
at a later date just as the Biotite-Hornblende Granite
was formed from the Biotite Granite. Some aspect of
the rocks indicate the probability of such origin,
for example: The diorite, as described earlier (fig. 4)
may develop locally large phenocryst-like crystals
of potash feldspar and then the rock resembles the
fayalite-bearing rock, in the same way that rocks
resembling the Biotite-Hornblende Granite occur as
sporadic patches within the Biotite Granite.

The rapid gradation between the Biotite-Hornblende
Granite and the Fayalite-Quartz Monzonite observed by

Bain (1926) and the present writer could be explained as being due to microclinization of two sharply different rocks like the Biotite Granite and the Quartz-Diorite.

It is, however, difficult to see why, if such were the origin, there should be so much difference in the colour of the microcline crystals from the Biotite-Hornblende Granite and that from fayalite-bearing rock in spite of their great similarity under the micro-scope. Further, the contact between the medium grained Biotite Granite and the Fayalite-Quartz Monzonite shows that the latter had behaved intrusively towards the former: and this suggests a second possibility, namely: that the fayalite-bearing rock was formed by hybridisa-tion of the Biotite-Hornblende Granite with a solution rich in ferrous iron. This is supported by many features of the rocks. The microcline of the fayalite rock is very similar to that of the Biotite-Hornblende Granite and a stained specimen (Plate 21, figs. A & B) shows that in both the crystals are arranged in approximately parallel lines, though this is less marked in the Fayalite-Quartz Monzonite. This suggests that the rock when soaked with the diluted basic solution remained as solid crystals in a mush not mobile enough to disturb the orientation of the

feldspars.   The plagioclase with bent lamellae could have been deformed at this stage and the small clustered mosaic aggregate of equant plagioclase are possibly formed at the same time.

The arrangement of the ferromagnesian minerals of the Fayalite-Quartz Monzonite suggested crystallization or recrystallization in limited spaces bounded by quartz and feldspar (Plate 24).

The green colour which, as suggested earlier, was due to ferrous iron staining the feldspar and quartz could be the result of long impregnation by a pore fluid rich in ferrous iron.

The diorite is thus either crystallized directly from a magma or by an admixture of basic material with the surrounding rocks.   At the great depth at which solidification took place, a great problem of volume is involved except if the magma were of small amount.   It is therefore conceived that the magma from which the quartz diorite was crystallized might have gradually worked itself into some pre-existing rocks, displacing unwanted minerals such as the alkali feldspars and quartz and incorporating others that are more stable in itself, for example the plagioclase and ferromagnesian minerals.   This incorporation would

involve partial or whole recrystallization. The irregular zoning described from this rock could be the result of this as might the presence of bent and deformed plagioclase crystals. The large porphyro- blast-like ghost microcline crystals described from the rock may be relic skeletal crystals; and such pseudomorphic preservation of their original outline by plagioclase is believed a corroborative evidence of this. Further some of the diorite retained the gneissose structure of the Biotite Granite or Gneiss which was displaced by basic material (ME 208, Plate 43 f. A).

MacGregor and Wilson (1939) made a study of many areas of granitization and demonstrated that the general trend in this process is the transforma- tion from pelitic and metamorphites through granite towards the composition of diorite. They concluded that granitization is effected by this upwards, advancing diorite magma. The petrogenesis of the Bauchi rocks is in accordance with this view and the writer is partly in agreement with it.

The source of the dilute magma itself is not quite understood, but while this can not be conclus- ively substantiated the hypothetical representation

of the evolution of these rocks (Fig.19) showed that
it is quite conceivable that the basic material
released in granitization has largely contributed this
basic material.   Thus further suggesting that the whole
process is one of reorganization of components in an
attempt to gain equilibrium.   This view is partly in
agreement with Ramberg (1951), but it appears that
these rocks have some pore fluid imparting to them a
degree of mobility.   This increased pore fluid may
originate from rocks undergoing transformation to
eclogite in the deeper zone and such a solution may
carry excess ferrous iron since eclogite is character-
ised by high MgO/FeO ratiox and very low water.

Metamorphic Facies Control of the Fayalite Rock and the Charnockitic Quartz Diorite.

The metamorphic facies concept is not restricted
to metamorphic rocks but is equally applicable to
rock crystallizing from magma or "migma".   The Charnoc-
kitic suite has been held as belonging to granulite
facies and characteristic of such an environment.

The calcsilicate rocks commonly intercalated
with the schists within the migmatites area gave an
indication of the grade of regional metamorphic facies

by their assemblage. The modal composition of these
rocks is shown in Table 4. From this the character-
istic assemblage is: Ferrosalite - grossularite -
scapolite - plagioclase (bytownite) - quartz. Ferro-
salite has crystallized in place of diopside possibly
due to high Fe/Mg ratio. In some specimens scapolite
appears in place of some plagioclase. The genesis of
scapolite is still little understood but its occurrence
in place of anorthite is common under condition of
granulite facies (Fyfe et al, 1958). The above
asse mblage is analogous with the assemblage diopside -
grossularite - bytownite - quartz which is characteristic
of the sillimanite almandine facies, (Fyfe eta al 1958).
The presence of subordinate scapolite partly represen-
ting the plagioclase however, suggests a transition
into granulite facies perhaps not completely attained.
Again, the quartzo-feldspathic assemblage, microcline -
oligoclase - biotite -quartz almandite also represent
the almandine amphibolite - granulite facies and the
feeble development of some perthites points to transi-
tion towards granulite facies.

The assemblage in the charnockitic Quartz-Diorite
is microperthite - plagioclase - ferrohypersthene -
ferro-augite - hornblende - biotite and is to a degree

analogous with the quartz - orthoclase - Hypersthene (garnet - plagioclase) assemblage of granulite facies and corresponding to charnockite (Turner and Verhoogen 1951), but complicated by the presence of hornblende and biotite. "Charnockites, however are not always associated with rocks of the granulite facies" (Pichamuthu 1953 p. 147) but are nevertheless products of the highest grades of metamorphism. Apart from their mineralogy, their colour distinguishes them from the surrounding rock which are usually claimed as belonging to the same general metamorphic facies and this may indicate that they have undergone some special conditions not experienced by the surrounding rocks.

The assemblage in the fayalite-bearing rock is andesine - fayalite - hedenbergite - hornblende - microperthite - quartz. This has no analogy in the assemblages listed by Turner and Verhoogen (1951) and in those given by Fyfe, Turner and Verhoogen (1958), but the presence of microperthite, normally associated with rocks of charnockitic affinity, and its colour suggests conditions not far from granulite facies.

Stability of Fayalite - Hedenbergite - Quartz.

Bowen and others (1933) made a study of the system

$CaO - FeO - SiO_2$ and show that hedenbergite is stable
at temperature below 965°, "Above this temperature it
inverts to a homogenious solid phase" which is one of
the Wollastonite solid solutions. This inversion
temperature can be expected to be lowered by water
vapour under pressure, but it is significant that
hedenbergite is formed as a solid phase from Wollas-
tonite solid solution. The inversion temperature under
natural conditions, especially with the presence of
water, could be expected to be lowered, coming within
the range of temperatures attainable in the pyroxene
hornfel facies. (fig. 21)

Let a suite of rocks be in euqilibrium at
amphibolite-granulite facies, the removal of load
pressure, and the introduction of fluid from the
dehydration process in the transition zone towards
eclogite will tend to bring the rock suite in to the
broad transition field between amphibolite-granulite
and the two hornfelses. (The exchange of Ca -Fe-Mg
for K-Al-Si in the overlying rocks to form migmatites
and granites might have resulted in a lowering of load
pressure in this way.) During the formation of the
Fayalite-Quartz Monzonite and the Quartz-Diorite both
of the above conditions are probable, and it may be

suggested that the charnockitic assemblage represent such superpostition of hornfels facies on amphibolite-granulite facies and that the stippled area (Fig. 21) may represent the field of charnockites and the Fayalite-Hedenbergite suite. The exact relationship between the two is unknown.

The Medium-Grained Biotite Granite.

This rock has all the characteristics of the Biotite Granite in the migmatitic series: microcline porphyroblasts, lineation structure, and numerous narrow granitic dykes, sometimes agmatitic. Unlike those of the Biotite Granite, the porphyroblasts are slightly larger and the rock to a certain extent approaches the greenish colour of the Fayalite-Quartz Monzonite and the Quartz-Diorite on which it appears to sit as a roof pendant. Generally it is much richer in biotite than the fine-grained Biotite Granite.

The rock was described by Bain (1926, p. 46) as a hybrid rock resulting from part absorption of "the magma" by the country rock and he described it as hornblende rock. Actually the hornblende occurs only locally and biotite is the most abundant and most

persistent ferromagnesian mineral.

The Fayalite-Quartz Monzonite ends in an unchilled sharp contact against this rock. It is therefore suggested that at the margin with the Quartz-Diorite where the Fayalite-Quartz Monzonite was sufficiantly soaked with water to become locally mobilised it behaved intrusively towards the Biotite Granite, impregnating it with some of the fluid though not enough to achieve complete homogenization but sufficient to alter its general appearance and texture. Under the conditions of soaking abundant biotite has crystallized.

The Medium-Grained Biotite Hornblende Granite.

This rock does not feature in the map or classification of the rocks of Bauchi district by Bain (1926). Its position in the rocks of Bauchi is uncertain, but from the variable texture and colour, and from the nature of the contacts which in some places are sharp and unchiled and in others indefinite, it is thought this rock could represent the result of local mobilization of the Biotite Gneisses and Granites in which they occur.

Under the conditions of Amphibolite-Granulite

facies in which these rocks are formed, the addition
of sufficient water and volatiles might cause local
mobilization. There is no evidence in the rocks that
these conditions are met; the suggestion is only
tentatively advanced.

CHAPTER VII   THE PETROLOGY OF DYKE ROCKS.

General Statment

The age relationships of the dykes in the Bauchi
district are difficult to establish due to lack of
definite stratigraphic horizon. No dependable age
classification was thus possible. The principal
dykes include dolerites, gabbros, and trachytes.

The Dolerite Dykes.

The dolerite dykes are probably the youngest
rocks in the area (Bain 1926) with the possible
exception of the Soda-Trachyte dykes. They are found
cross-cutting all members of the Older Granites.
They rarely exceed one foot in width, the majority is
about 10 inches wide. Frequently a displacement of
about the width of the dyke occur (Fig. 20a) Commonly
some of the larger dykes branch, embay the country
rock, reuniting again to form a single intrusion
(Bain 1926). The best example of this is north of
the Zungar hills where they fan out into cataclastic
blocks and then re-unite (Fig. 20b) Some of the larger
dykes are shown on Map (A).

Three of the larger dolerite dykes contain large

xenolith of the country rock. One is immediately south-east of Tiruin, another is 2 miles north-west of Tiruin and the third is about $1\frac{1}{2}$ miles west of the Baskin Hill. These dykes are indicated as xenolithic dykes (Map A). They show baking effects on the enclosed rocks; these are described below.

Petrography of the Dolerite Dykes.

In hand specimen the rocks are dark, dense, very fine grained and frequently porphyritic. Under the microscope diabasic texture is seen. When porphyritic, phenocrysts of plagioclase, pyroxene and olivine (commonly altered to antigorite) occur in clusters. The diabasic ground mass is composed of small laths of plagioclase, scales of brown biotite, fibrous flakes of antigorite and small grains of pyroxene.

The plagioclase is andesine ($Ab_{47}An_{53}$). It occurs in small laths in the ground mass and as elongated plates, frequently with combined Carlsbad and Albite twinning. The pyroxene is identified as ferro-augite (Table 8), of composition $MgSiO_3$ 32.0%, $CaSiO_3$ 23.0% and (FeTi) SiO_3 45% (determined on Hess's (1949) diagram). Olivine is almost always altered to antigorite in part or completely.

The xenolithic dolerite dykes contain fragments of the surrounding biotite gneiss. These inclusions vary from about 25sq. inches to microscopic xenocrysts. Under the microscope the diabasic groundmass remains the same but in addition to the usual phenocrysts there are numerous xenocrysts of quartz and feldspar. The quartz xenocrysts are remarkably clear. Thye are resorbed into rounded grains and are invariably surrounded by felted mass of biotite, sericite and possibly chlorite. The xenocrysts of feldspar on the other hand are not so sheathed but are more or less always clouded with alteration products.

The xenoliths are composed of quartz and feldspar, both with amoeboid outline. Intergranular corrosion is indicated by sugar-textured veins of quartz between the grains and by the reaction mantle around the feldspars. Biotite was scanty and has been decomposed into unidentified mass. All the feldspars in the inclusions show some clouding and cracking and the plagioclase near the contact is recrystallized into a feathery aggregate.

The Trachyte Dykes.

There is a system of striking trachyte dykes

occupying a narrow belt in the north-west of the district (see Map A).

The dykes vary in width from one foot to ten feet, and in length from twenty yards to over one mile. They are generally vertical with pronounced block-jointing. The jointing and their beautiful greyish-green colour makes them the most valuable building rock in the area, the most worked dyke being that running past the Bauchi administration building and crossing the Jos road towards the village of Shadawanke. (see Map A)

The rock is very fine-grained, dense and of greyish green colour. It may show xenoblastic structure. Under the microscope it is seen to be composed of alkali feldspar, aegirine, riebeckite and a small amount of quartz. The rock generally has trachytic texture and may show flow structure (Plate 44 f. A).

The feldspar is in small subhedral plates twinned according to Carlsbad law. It has parallel extinction. It is the only feldspar present except when the rock contains xenocrysts of other feldspars clouded with alteration. The pyroxene is aegirine and the amphibolite riebeckite; these are the only ferromagnesian minerals observed. Quartz occur in small pools, sometimes, with a fringing cluster of epidote. A small

amount of green biotite was also observed.

This rock is evidently sodic, and is unusual in the Bauchi district where the rocks tend to be more potassic. MacLeod thought that they might be related to the Tertiary volcanic rocks of Benue Valley i.e. Wase Rock (private communication). The writer is more inclined to classify them as being related to the rocks of the Younger Granite cycle, some members of which are very sodic. The nearest intrusion of Younger Granite is only about fifty miles to the west of Bauchi.

The Gabbroic Dykes.

Two dykes of gabbro were found. They are of interest partly because of the profound alteration of the adjacent gneiss and partly because of their petrography. In hand specimen the rock is medium grained. The feldspar has been altered and is coloured greyish or reddish. Under the microscope the rock is composed of clouded feldspars, titaniferous clino-pyroxene, red-brown amphibole, brown biotite and olivine altering to antigorite. Accessory amounts of apatite and iron ores are present.

The feldspars are orthoclase and plagioclase.

The latter are completely sausuritized and the composition cannot be determined; the intense alteration of the feldspar indicate a high water content of the magma. The presence of orthoclase in association with the assemblage biotite - olivine - clinopyroxene makes the rock closely related to kentallenite the only recorded occurrence of which are known in Scotland and Siberia.

The pyroxene is weakly pleochroic from lavender or pinkish colour to pale yellowish-green. It has the same optical character as the pyroxene of the dolerite dykes (Table 8) but is of deeper pink colour and is therefore titaniferous ferro-augite of the composition $MgSiO_3$, 32.0%, $CaSiO_3$, 23.0% and $(FeTi) SiO_3$, 45% (Hess (1949) diagram). It is partly altered to chlorite giving it a ragged outline.

The olivine is in equant grains and may be partly altered to antigorite and is more or less always enclosed by pyroxene. Biotite is reddish brown and occurs in large elongated plates, partly altered to chlorite.

The amphibole is deep reddish brown and commonly pleochroic to a pale yellowish colour. This unusual colouration is especially marked in one specimen

(ME 219) It is believed to be a lambprobolite
produced by the oxidation of the iron of common horn-
blende probably through the action of hot gases.
(Rogers and Kerr 1942 p. 289). It may, like the
pyroxene, be of ragged outline with alteration to
chlorite.

Apatite is a common accessory mineral and occurs
in long narrow rods cutting across or contained within
the other minerals.

The immediately overlying gneiss is baked brick
red and the potash feldspar recrystallized into
irregular pegmatitic masses. Further out, on both
sides of the dyke sporadic porphyroblasts of micro-
cline are developed. Under the microscope the over-
lying rock was found to be greatly altered. The
feldspars are turbid and are rimmed by a felsitic
selvedge at their contacts with quartz (Plate 44 f. B).
The biotite is decomposed to chloritic patches and ore.
Quartz appears to have been recrystallized. Some
sections show strong development of micrographic
texture (Plate 44, f. B) indicating the action of hot
solutions. These textures are very much similar to
those described by Reynolds (1948) from a granophyre
on Slieve Gullion, Ireland.

Other Dykes.

Some granitic dykes are found just outside the
mapped area.   One is a fine grained biotite granite,
similar in appearance to some of the Biotite Granite
of the Younger Granites Complexes, especially in its
paper-white feldspar.   The other is a porphyritic
granite closely resembling some of the porphyritic
Younger Granites.

TABLE 11

Optical Characters of the Pyroxenes and Amphibole from

Dykes.

Z	n. d.	n. d	1. 713
Y	1. 710	1. 710	1. 695
X	n. d	n. d	1. 693
Z-X	n. d	n. d	0. 020
2V	+46°	+46°	-72°
EXT X C	37°	38°	14°
X	Light green	Light green	-
Y	yellowish green	yellowish green	-
Z	lavender pink	light pink	-

1. Pyroxene from Gabbroic dyke (ME 164)

2. " " Dolerite dyke (ME 166)

3. Amphibole from Gabbroic dyke (ME 219)

CHAPTER VIII   THE CATACLASTIC AND ALTERED ROCKS.

Cataclastic Rocks.

Several zones of cataclastic deformation
representing various degrees of crushing are observed
in the field (Map A). One such zone at the west of
the Zungar Hills and about a mile south of Rugar Ju
inselberg, falls outside the maps (A and B) but lies
within the Bauchi Batholith. It is described here
because it represents an early stage of crushing not
found in the area covered by the map and thus fills a
gap which would otherwise be missing between the
intensively deformed and the underformed rocks.

This cataclastic rock (Plate 45) shows large
pinkish lenses of feldspar visibly crushed, surrounded
by strands of quartz and dark minerals which appears
to flow round the feldspars. Under the microscope
the rocks has a groundmass of cataclastic texture
with seriate augen of feldspars. The larger of the
augen are of potash feldspar and are coarsely perthitic
with patch perthite developed. The smaller augen are
of plagioclase; these are more rounded, frequently
untwinned or poorly twinned, and are slightly clouded
by alteration product.

The groundmass is of rather granular texture and is composed of quartz and feldspars. In the microcline of the groundmass gridiron twinning is often very conspicuous. Sparse, finely-shredded greenish flakes of biotite are disposed in parallel lines, and occasional clustered plates of biotite and hornblende may be found. There has been some recrystallization and the augen and the groundmass are commonly so mutually intergrown that it is difficult to say whether the groundmass invades the augen or vice versa.

The groundmass is divided up by elongated, optically discontinuos aggregate of quartz. These rod-like aggregates of quartz often show sharp truncated borders against the groundmass, contrasting with relationship between the augen and the groundmass. The quartz exhibits some slight wavy extinction.

The specimen from Miri village (ME 159, Plate 46 f. A) represent a more advanced degree of crushing. The augen are small, more uniform and seperated by wider area of crushed groundmass. The eye-like feldspars project along their longer axes into tail-like trails of crushed feldspar. Large irregularly scattered patches of hornblende can be seen and the groundmass is dark with biotite. Under the microscope,

the augen are less coarsely perthitic, being mostly
of string type. They show similar replacement
structures towards the groundmass. The groundmass is
as described for the earlier specimen but strewn with
fine plates of biotite with parallel orientation.
Biotite also occur in large clustered masses associated
with rounded knots of hornblende. It may also occur
in narrow, ragged linear clusters.

The quartz rods are shorter and are much more
undulatory than in the previous specimen; they are
also not quite as sharply demarcated from the
surrounding groundmass. An idiomorphic mineral with
strong relief, believed to be zircon is present.

East of Tiruin village a more intensely deformed
zone involving the biotite gneiss is found (ME162).
The rock has become banded and consists of alternating
dark and light (pinkish) zones. No augen is discern-
ible in hand specimen but under the microscope, they
could be seen and are mostly plagioclase of almost
an oval shape. Fine plates of biotite lie flat around
them forming a thin discontinuous mantle. The plagio-
clase shows marked strain extinction.

The groundmass is lepidoblastic and consists of
alternating biotite-poor and biotite-rich bands. In

the biotite-rich part, fine plates of biotite with parallel orientation are generously strewn over the groundmass. In the leucocratic zones spare ragged lines of muscovite are present. The quartz is elongated and arranged in parallel lines forming disjointed rods. The crystals show very strongly undulatory extinction.

Near this zone is a still more intensely deformed rock, nearly a mylonite (ME 163). The crushed groundmass is of a very fine sugary texture with the individual minerals difficult to distinguish. Long rod-like aggregates of optically discontinuous quartz have strong undulatory extinction and show a parallel arrangement. A few augen remain and these have attained the perfect oval shape (Plate 47, f. A) by which they are able to resist shearing stress.

As in the preceding zone, dark biotite-rich zones alternate with light bands containing muscovite.

The other deformation areas indicated on the map (A and B) are examples of one or the other of the varieties described above.

Discussion of the Cataclastic Deformation.

Quartz is the most freely soluble mineral in

non-calcareous igneous rocks of the types described above.   (Harker 1932 pg. 170)   In the early stages of stress it is therefore not surprising that it is the earliest mineral to become re-oriented, lying in the position of least strain in elongated rod-like shape. This recrystallization has probably been effected by solution at points of greatest pressure and redeposition along points of lowest mechanical stress. This may account for the sharp truncating contact with the rest of the groundmass.   Such a process may necessarily involve displacement of other minerals and their recrystallization until perfect adjustment to the strain is achieved.

Intergranular fluids might be very important to rock adjustment during cataclasism, not only for the solution and redeposition of the more soluble minerals but as a medium for diffusion of the components of the less soluble material during reconstitution.

Turner and Verhoogen (1951 p. 373) attributed cataclastic rocks, augen gneisses and mylonites to kinetic metamorphism in the strictest sense and emphasized that their cataclastic structure is "determined by crushing and differential movement of the component grains without important recrystal-

lization of old, or growth of new, minerals". Such
crushing and differential movement necessarily involves
recrystallization; this is demonstrated not only by
the elongated rods of quartz but also by redistribution
and orientation of biotite flakes.   Fyfe and Turner
(Fyfe et al, 1958 p. 180) have suggested that the
influence of stress-pressure may be considerable
though it cannot yet be evaluated and suggested that
"increase in stress at constant load and water pressure
and constant temperature" could cause the transition
of amphibolite to granulite facies, such a transition
if really achieved would necessarily involve the
breaking down on one set of minerals and the crystal-
lization of others.   The development of muscovite in
the more seriously deformed zones is the Bauchi
cataclasites is evidence of this as is the development
of sericite and chlorite in some others.   Harker (1932,
ps. 172-176), mentioned several types of such
mineralogical changes.   It is considered that cata-
clastic deformation is likely to be attended by
recrystallization.

The Altered Rocks.

Apart from the altered gneisses overlying basic

dykes already described, some altered rocks are found
locally. The most extensive of these is the area of
silicification near the Jos road to the south-west of
Miri village (Map A).

A small conical hill marks the centre of this
alteration zone. Quartz bearing solution appear to
have been injected into the Biotite-Hornblende Granite.
The alkali feldspar porphyroblasts are closely
injected with thin strands of quartz (ME149) and
are themselves altered into a yellowish powdery
mineral which thermal analysis (Fig. 25) shows to be
sericite. Open cavities are filled with quartz
crystals.

Under the microscope the altered rock (ME149)
is seen to be made up of euhedral to subhedral crystals
of quartz (Plate 48, Fig. A) which are free of
inclusion, fractures or strain extinction. Some
euhedral crystals may have a narrow turbid selvedge
of altered appearance along and just inside its margin.
Felty patches of sericite are dusted over the large
quartz masses.

Lower down on the side of the hill the quartz
was injected as branching veins about $\frac{1}{2}$ - $1\frac{1}{2}$ inches
wide into the granite embaying, impregnating and

altering it (ME 148). The original feldspar crystals
are marked by reddish oblong areas, found to be sericite
impregnated with haematite. Under the microscope it
is seen to be much similar to the first specimen (ME
149).

This alteration is continuous in a south-westward
direction marked by a number of low hills. Towards
the edge, the large alkali feldspar porphyroblast
appear to be still intact but altered to a brick red
colour (ME 150). Small bodies of purplish-red
haematite and yellowish patches of sericite can be
seen giving the rock a veriegated appearance. Under
the microscope large masses and microveins of quartz
are found surrounding the altered feldspars. The
microcline is still recognisable and is clouded with
haematite-impregnated alteration masses (giving the
brick red colour) and injected with thin microveins
of quartz. Dark patches of haematite can be seen
within it. As in the other examples no trace of the
original ferro-magnesian minerals is found except
rare patches of limonite and haematite staining. A
similar zone of siliceous alteration was found between
the aerodrome and the south end of the Bauchi city
wall, and smaller areas occur south of Kasuna hill.

In general they are quite similar to the above
alteration and are therefore not described seperately.

Epidotization.

This alteration covers about 100 sq. yards at the
west end of Buli hill (Map B). In hand specimen, the
Biotite Hornblende granite is altered to a handsome
rock coloured pink and green. The pink corresponds
to feldspars and the green to epidote crystals, while
quartz is colourless (ME 151).

Under the microscope, the altered rock is seen
to be composed of microcline, plagioclase, quartz
and abundant epidote. The microcline porphyroblasts
are perthitic and clouded by alteration products,
possibly sericite. The plagioclase, in grains of
various sizes, is also so turbid with altered material
that the outline of the grains may often be indefinite.

Quartz occurring as clear pool-like grain, is
within itself optically continuos and shows no strain
shadows.

From the surrounding feldspars swarms of long
plates of epidote project into the pools of quartz
as though into a cavity (Plate 47, f. B) whiles
clustered plates may form "islands" within the quartz.

Sericite is present in bent fibrous to felty material on the feldspars. There is no iron ore and no trace of any original ferromagnesian minerals.

Tourmalinization.

Tourmaline crystals are occasionally found in the pegmatite dykes (Plate 48, f. A) and some graphic granite dykes show complete replacement of feldspar by tourmaline (Plate 48, f. B) These are probably not alteration in the strict sense, but about half a mile north-west of Guru hill, in the Biotite Granite, tourmaline is observed replacing the plagioclase of this rock.

Chloritization.

Zones of hot solution alteration are occasionally found in small narrow patches in the area. These probably reflect the intrusion of dykes below the present level of erosion. One specimen (ME 246) from west of Maguma hill (Map A) is the original Biotie Gneiss altered to a greyish colour. Under the microscope all the feldspars are seen to be deeply altered to an unidentifiable sieve-textured mass. Quartz occur as veinlike bodies of granular mosaic. Surround-

ing the feldspar broad rims of micrographic texture
are developed.

The ferromagnesian minerals are altered to
chloritic masses with segregations of iron ore. Some
vermiculite is formed after biotite.

Another specimen (253) from the eastern foot of
the Inkil hills is very similar to the above except in
the absence of the micrographic selvedge round the
feldspars. Shreds of vermiculite may alternate with
biotite.

Discussion on the Alteration in Bauchi District.

In the silicification, the biotite and hornblende
are decomposed and reduced to haematite in the early
stage to give the partly altered feldspars a reddish
colour, but in the more intensely silcified specimen,
there is no trace of the original ferromagnesian
minerals. Though the metamorphic conditions are not
definitely known, it can be inferred from the
decomposition of ferromagnesian minerals to haematite
that the silicification is a high temperature, while
the epidotization possibly indicates low temperature
alteration.

CHAPTER IX   CONTRIBUTION TO PETROGENESIS.

The Relationship between the Older and the Younger Granites.

The absence of definite stratigraphic horizons
makes age determinations of the Older and the Younger
Granites difficult.   Dating by radioactive methods has
been attempted on the Younger Granite; so far the
results are not satisfactory. (Jacobson and others,
1956, p. 6.) No age radioactive determination has yet
been attempted on the Older Granites.

Jacobson and others (1958) mentioned that the
Younger Granites cannot be related to any orogenic
cycle; the Older Granites are not known to belong to
any.   On basis of the intrusive and disconcordant
contacts between the Younger and the Older Granites
it is commonly held that the later are older and
belong to an entirely different petrogenic cycle,
the usual assumption being that the two complexes
have nothing in common.   The present investigation
showed that the Bauchi older granites are most likely
evolved by a progressive metasomatic transformation of
metasedimentary rocks, and that there are certain
similarities between the members in one complex and
those in another; the most striking being the

occurrence of Fayalite-Hedenbergite-amphibole acid
rocks in both.

Under the high temperature and pressure condition
of metamorphism corresponding to amphibolite-granulite
facies in which the Bauchi rocks are believed to have
been formed by metasomatism, granitic rocks are not
far from melting if enough flux and water were present.
(Fyfe and other 1958, Goranson 1932). One distinctive
feature of the Younger Granites is the high content of
volatile in their magma, some of the granites have as
high as 1.69 per cent content of fluorine, many show
normative fluorine, and the mica from the biotie
granites have as high as 5.02 per cent fluorine, (Jacob-
son eta al, 1958 p. 14-16). They are also associated
with abundant topaz tourmaline and some cryolite. From
the common occurrence of greisen zones, and other
features, the magma giving rise to the Younger Granites
most probably contained much water and other volatiles.

The areal proportions of the different rock groups
of the Younger Granites can be summarised as follows:
(Data by Jacobson and other (1958, p.7))

Biotite Granite 56%

Rhyolite 19%

Riebeckite granite 12%

Amphibole-fayalite granite 8%

Basic and intermediate rocks 6%

This order of abundance, excepting the Riebeckite Granite, is comparable with the order of abundance of similar rocks in the Older Granites, especially in the abundance of Biotite Granites in the Younger Granites corresponding to the vast amount of migmatitic Biotite Gneisses and granites.

Through the kindness of Dr. Jacobson, the writer has been able to see some sections of the Amphibole Fayalite Granite and porphry from the Younger Granites. They have structures which the writer is inclined to believe might mean that they were crystallized from magmas derived by incomplete melting of the basement complex:

In the hornblende fayalite granite (L1.1623) from Sha, the plagioclase occur mostly as oblong cores with irregular rounded outline, and surrounded by micro-perthite with dusty brown staining. (Plate 48 f. B). The irregular shape of the ferromagnesian minerals and that of the plagioclase is typical of resorption effects. All minerals show intense corrosion with quartz developing large areas of micrographic texture (Plate 48, f. B).

According to Bowen (1928 p. 229-230) such
mantling with orthoclase indicates a reaction
relationship between basic plagioclase but such
relationship "must disappear before a sodic plagio-
clase is reached". This Bowen explained by a ternary
diagram (1928 p. 231) of the system, orthoclase -
anorthite-albite. The orthoclase mantling in this
rock of the Younger Granite is at variance with the
deductions of Bowen. For one thing the magma of this
rock was obviously not potash rich and for another the
core plagioclase is sodic and not basic, most being
oligoclase (Ab80) This mantling might be interpreted
as due to some plagioclase crystals, only partly
resorbed in a potash rich magma which could be expected
to result if all minerals but the plagioclase of such
a rock as the Fayalite Quartz Monzonite were completely
melted.

Of the Younger Granites members, the Riebeckite
Granite has no counterpart in the Older Granites. Both
the Older and Younger Granites have low magnesia and
the essential chemical difference between the two is
that the Younger Granites tend to be soda-rich. (Table
10). This does not alter the probability that the
magma of the Younger Granites were derived from the

rocks of the Older Granites. There appears to be a condition in the nature of the mechanism leading to the generation and emplacement of ring-dyke complexes which favours the accumulation of soda and with few exceptions, ring-dyke complexes of granites or carbonatites have soda-rich phases; and this may be due to high relative mobility of soda which favours its concentration in volatiles and water.

The sequence of petrological events leading to the development of the present rock series in Bauchi, described in this work must have occurred over a wide extent of Nigeria as demonstrated by the similarity of rocks and petrology evident from the works of King and deSwardt (1949) and deSwardt (1953). In areas now containing Younger Granites, the metasomatic processes might have been complicated by the accumulation of large amount of water, fluorine and other volatiles, fluxing the rock with consequent partial to complete melting. The resulting magmas would develop high internal (F, H_2O, CO_2) pressure, resulting in a series of explosions, subsequent subsidences and emplacement of the magmas as cone sheets and ring-dykes in higher level as described by Jacobson and Others (1958).

Thus the magma of the Younger Granites could have been derived from some Older Granite rock series similar to those of Bauchi. The nature of the contacts of the Younger and the Older Granites, sharp but without contact metamorphism suggest that the magma was intruded into preheated rocks and it is possible that the magma might be the culmination of a metamorphic process which had heated the rocks.

The occurrence in the Younger and Older Granites, of rocks of similar mineralogy, though different texture and structural setting becomes understandable if the magmas of the Younger Granites were derived from the rocks of the Older Granites as suggested.

Granites and Granites.

Read (1948) discussed the problem of granites of different genesis and recently it has been more closely examined by Walton (1955), Perrin (1956) and Marmo (1956). Most geologists are now agreed that there are granites and granites, some formed "one way", others by some different "ways". The points of disagreement are essentially two; the extent to which the different "ways" are operative, and the relation-ship between the different processes by which rocks

of granitic composition are believed to be formed.

During the discussion on the genesis of the Bauchi rocks, it is suggested the increasing degree of metamorphism with depth should ultimately involve upward migration of the alkalis into rock of granulite and amphibolite degree of metamorphism. The stability of the alkalis presumably become sharply limited at some point beyond the granulite. This alkali metasomatism, especially of potash, is the dominant process in granitization and migmatization in Bauchi and throughout the Nigerian Pre-Cambrian plutonic granite areas, and produces rocks that are strikingly alike. Similar processes are belived to have produced large bodies of granite in other parts of the world where Pre-Cambrian plutonic granites are exposed. Therefore, in agreement with Read, these large bodies of granite are considered to be the products of regional metamorphism.

Under the metamorphic conditions of Amphibolite-Granulite facies in which the Bauchi "Granites" were formed, rocks of granitic composition are not far from melting in the presence of abundant water and volatiles. Many of the high level granites, termed disharmonious granites by Walton (1955) often show evidence that their magmas are rich in volatiles; and these magmas

might have resulted from the complication of the
regional metamorphism by local concentrations of water
and/or other volatiles.

Thus though "experimental study" (Bowen and Tuttle
1958) confirms the relationship between magmatism
and metamorphism, contrary to the implication of
Bowen and Tuttle (1958, p. 126), magmatism might be the
product of regional metamorphism which has been
complicated by accumulation of volatiles.

Bowen believed that magmas rarely contain amount
of super-heat and actual measurement and various other
determinations (Larsen 1929) supports this view and
showed that temperature of granite magmas are of the
general order of what could be expected if they mostly
have originated from highest degrees of regional
metamorphism. The writer is thus readily in agree-
ment with Read (1948) that most granites "may likely
be of one connected origin", and finds it difficult
to imagine the generation of large quantity of granitic
magma or any magma except by melting of related rock.

The process leading to the melting of granites in
the upper crust, depending on local accumulation of
water and volatiles appear to be much more limited,
and granites of undisputable magmatic origin (i.e.

the Younger Granites) are of much smaller extent than
the plutonic granites of metamorphic origin. This is
true of African "Later Granites" which are generally
of much smaller area than the plutonic series in
which they may occur (Map C).

Emplacement of Granite.

One of the problems of petrogenesis is the room
factor in the emplacement of large masses of granites.
The present study showed that Bauchi Batholith has
most probably been emplaced by metasomatic processes
under conditions that were not far removed from a
magmatic state, so that until closely examined and
studied in relation to the migmatite, its metasomatic
aspects are not revealed and several of the rock types
could readily be interpreted as having crystallized
directly from a magma.

There has possibly been a slight volume increase,
but this could have been relieved by doming of the
overlying rocks with consequent development of zones
of tensional fractures.

In the Bauchi area such tensional zones probably
occurred, though were not as open fractures; these
have controlled and induced the development of

pegmatites. The constant association of outlying swarms of pegmatites with large granite batholiths showed that similar operations may well have been in force in the emplacement of many granite bodies.

Under the conditions of large concentration of volatiles and water the internal pressure is possibly sufficiently high not only to fracture the overlying rocks (being higher than load pressure) but also to move the magma upwards by stoping of fractured fragments. Thus there may be inherent in the forces which generate granitic magmas a mechanism for the emplacement of the magma.

Large bodies of granite could be formed in place in a condition sufficiently near magmatism to possess some mobility but the writer does not consider that such rocks have been sufficently molten to be called a magma and they could never have moved far from the place where they were made, if at all. The undisputable magmatic types could only be of comparatively small bodies; ring dykes, stocks, pipes and lacoliths, they could attain a batholithic size only by coalescence of such small bodies.

Granitic Rock of Contrasting Composition.

The contrasting composition of Bauchi rock is

believed due metamorphic rearrangement of rock
components. The writer believes that many bodies of
granites of contrasting composition, normally regarded
as differentiated bodies might be similarly explained.
The writer questions the possibility of granitic
magma differentiating to produce three or more granites
of different composition, mainly from the cotectic
nature of its mineral aggregates, if possible it must
be under some rare and unusual conditions.

The Nigerian Ring-Dyke Complexes might be cited
as an example of differentiated granitic magma,
Jacobson and others (1958) appeared to favour this,
(see variation diagrams, Jacobson and others 1958,
p. 27). The repetition of the same series of rocks
present in the volcanic cycle during the intrusive
cycle might equally well be accounted for by composite
magmas derived from the melting of rocks of contrast-
ing compositions, similar to the Bauchi rock series.

Classification and Nomenclatures of Granites.

Granitic rocks are generally classified according
to the proportions of plagioclase, alkali feldspar and
quartz, and sub-divided on basis of ferromagnesian
minerals (e.g. acid charnockite). Rocks are often

described and discussed under the nomenclature of "granite" rocks which classified properly would be called granodiorite, adamellite, or even diorite and monzonite.

The writer's view is in sympathy with Chayes (1954) who suggested the need for a review of the classification of granitic rocks, but could not wholly share his view that "no classification or naming of granites should be attempted without abundant and reliable modal data". Not only are modal compositions only approximations, they vary, using the same specimen, from one thin section to another. When rocks are unusually coarse, as with the Bauchi rocks, one would need for each rock some hundreds of sections spaced over all outcrops, in order to have a reliable average modal composition and the coarser or more foliated the rock becomes, the more difficult becomes the problem of getting "reliable modal data".

The petrology of the Bauchi rocks suggests to the writer the need, in the classification of granitic rocks, for a nomenclature which represents easily determined rock characters and which can be usefully employed in the field mapping of granite complexes. Such a classification calls for the simplification

and clearing of the present "confused" system.
(Chayes 1954). Thus a rock could be classified as
granite when alkali feldspar is the dominant mineral,
except when quartz is scanty and it can be called a
syenite; diorite when plagioclase is the dominant
mineral except when quartz is very abundant and the
rock is a granodiorite. Rocks with roughly equal
proportions of plagioclase and alkali feldspar may
be called adamellite as is currently used.

Unusual mineralogical, textural or colour
varieties may then be indicated by prefixing the
special point of peculiarity. The above names are
very well established in the literature and recognised
as described above; what is being proposed is the
elimination of straight line boundary and such terms
as alaskite, charnockite, arendalite, endebite,
shonkinite and several others which may be considered
superfluous. Where granitic rock is abnormally dark
coloured and with significant genetic implication as
in the case of charnockites and the Fayalite-Quartz
Monzonite, the term "melanic" or some other term may
be subfixed. Thus acid charnockite will be Melanic
Hypersthene Granite and the Bauchi Fayalite-Hornblende
Quartz Monzonite simply Melanic Fayalite Adamellite.

These may usefully be employed in mapping and petrological descriptions.

Criteria in Petrogenesis of Granite.

Grout (1944) gave an impressive list of criteria that must be confirmed before the petrogenesis of a rock could be established. As Currier (1947) has remarked, Grout is not being realistic about the problem of granite genesis. The petrology of Bauchi showed how frustratingly equivocal the evidences available in a rock complex can be. As in most cases neither magmatic nor metamorphic origin of a granite can be absolutely proved, what could only be done is to weigh the various evidence in relation to more or less established Physico-Chemical facts.

The problem arises from the fact that most of the characters often obsefved in rocks of either genesis are functions of temperature and pressure, indirectly of depth, and only to a less degree, of the physical state of the rock mass at the time of formation. The knowledge that with only a little pore fluid, rock mass may be mobilized to have intrusive character has further complicated the problem.

The use of experimental data as criteria in

petrogensis may be misleading. Experimental studies
only serves to confirm or explain what has been
observed in Petrology but do not rule out Petro-
logical phenomena which it cannot explain. That
there is a close genetic relaionship between magmatism
and metamorphism is well appreciated and there is good
evidence for this in the field, recognised before
experimental studies, but contrary to the suggestion
of Bowen and Tuttle experimental studies, has not
established which gave rise to the other. While
regional metamorphism has stopped at the threshhold
of magmatism in Bauchi, it may well have transcended
to this field in the central part of Nigeria leading
to intrusive activity and what has made the difference
is the abundance of volatile concentration in one and
lack of it in the other. Thus magmatism may be
different from metamorphism only by degree of mobility.

These phenomena are functions of many variables
which are imperfectly known (Fyfe et al, 1958 p. 202-
203) and therefore could not be accuratêly taken
account of in the experimental studies of Bowen and
Tuttle (1958).

A set of criteria such as that assembled by
Grout (1944) could be applied as reliable guide to

study granites, but individual body of granite must
be studied by itself and the criteria for its genesis
derived from field studies and careful mapping and
lastly from petrographical and chemical studies.

Granites in general, like the Bauchi rocks do
not give absolute evidences of their origin and in
the discussion of their petrogenesis, even with
experimental studies, they do not give room for
absolute assertions.

The Origin of Charnockites.

The origin of Charnockites is as controversial
as that of granite, again because of the lack of
unequivocal characters. Holland (1900) who first
described charnockites, concluded that they are
igneous rocks, but conceded that some features of
the rocks were disturbing.

The problem of charnockite are recently reviewed
by Ramberg (1951), Pichamuthu (1953) and Howie (1955).
Ramberg (1951) suggests that charnockite are products
of degranitization, they are left behind after the
rise of the granitizing fluid, and further basified
by materials migrating downwards from zone of migma-
tization. Pichamuthu (1953), studying the Mysore

charnockitic rocks made an extensive review of
charnockite problem which led him to conclude that
charnockites are products of high-grade metamorphism,
"the basic bands and lenses in the gneisses were
converted into basic charnockite and the accompanying
gneisses received a charnockitic impress," a process
he termed charnockitization.   Howie's conclusions (1955)
are closely allied to that of Pichamuthu believing "that
these rocks represent plutonic igneous rocks which have
undergone slow recrystallization in the solid state
on being subjected to conditions of plutonic metamorph-
ism."

The exclusive association of charnockite rocks
with rocks of granulite (Ramberg, 1952) and Almandine
Amphibolite facies, (Pichamuthu, 1953, and Bauchi
charnockitic diorites), suggest that the rocks are not
simple igneous types as proposed by Holland (1900).
If they have had igneous origin they must have been
later subjected to metamorphism under high temperature
and pressure condition as suggested by Howie (1955).
The occurrence of acid Charnockites which can be
described as hypersthene granite makes it improbable
that Ramberg's degranitization hypotheses is the
dominant process in the production of charnockites.

The origin of the Quartz Diorite and the Fayalite
Quartz Monzonite is related to the general problem
of charnockite genesis. It was suggested earlier
that these rocks originated by infiltration into
granites and gneisses of basic components under a high
temperature and pressure conditions of metamorphism.
The greenish or bluish yellow-brown colour of the
feldspar and quartz is an invariable character of
charnockitic-norite rocks and presumably bears some
relation to their genesis. (From the piece of the
rock which when subjected to heat turns brownish red,
it had been earlier concluded in agreement with Howie
(1955,1958) that the colour is most probably due to
impregnation with ferrous iron.) In any case, the
colour shows that they have undergone some conditions
not shared by the surrounding rocks. Thus some
charnockites might have originated through the
infiltration into gneisses of basic materials rich in
ferrous-iron with consequent migration of the alkalis
which effected granitization at the higher levels,
and so produce more basic components. Obviously,
such rock will bear a mixture of metamorphic and
igneous characters and could with equal credibility be
interpreted as originating from metamorphic

recrystallization of igneous rocks (Pichamuthu 1953, Howie 1955), but the general conformable shapes of charnockite bodies (Pichamuthu 1953) shows that the charnockite might be originally part of the surrounding gneisses.

Metamorphic facies of Charnockites.

Charnockites are generally regarded as belonging to granulite facies of metamorphism (Ramberg 1951). Pichamuthu (1953) has demonstrated that Charnockites are not invariably associated with rocks of Granulite facies but may also be associated with those of Amphibolite facies. The Charnockitic rocks of Bauchi support the observation of Pichamuthu.

Though the rocks of Bauchi belong to the Almandine Amphibolite facies (in transition to granulite) if the charnockitic members of the rocks of the district have originated by infiltration of solution from below, it is unlikely that the charnockitic rocks themselves represent this metamorphic facies but would have been formed under a metamorphic condition to be found in the transition field between the Amphibolite-granulite facies on one side and Pyroxene horfels on the other as discussed earlier. (Fig. 21); This

suggestion is not considered proved and is only
tentative, but it appears probable and follows from
consideration of the independent variables in
metamorphism as presented by Fyfe and others (1958,
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A P P E N D I X

DETERMINATION OF MODAL COMPOSITION OF EXTREMELY COARSE GRANITE ROCKS.

The Biotite-Hornblende Granite and the Fayalite-Quartz Monzonites are extremely coarse, some of the large microcline porphyroblasts measuring nearly 4cm. in length. To get a reliable modal perecntage of the microcline in this rock, large hand specimens measuring about 6 x 4 inches were ground until flat and fairly smooth, and the smooth faces were then hetched for about 1 minute with hydrofluoric acid fume at about 30°. The specimens were stained by Keith method with sodium cobalti-nitrite solution (Keith 1939, Chayes 1952). The potash feldspar was stained yellow colour, the decomposed plagioclase was white, quartz was not affected and the ferromagnesian minerals are of greenish colour due to the biotite clustered with them. The stained surfaces were photographed and the results printed on 8 x 10 papers; the potash areas, stained yellow, appeared black, due to filtering effect of the yellow colour, and thus enhanced the contrast. The plagioclase appeared as white areas and the quartz as grey while the ferro-

magnesians were of a slightly darker grey.   With the

aid of the hand-specimen and a magnifying glass, the

contact lines of the constituent minerals were traced

in ink.

The modal proportions of the different minerals

were calculated from the results of point counting on

the photographs using a ruler at $\frac{1}{8}$ square per point.

In addition, some structures of the rock not

previously noticed in ordinary handspen and difficult

to appreciate in thin section were brought out strongly;

as for example, the lineation and crystalblastic

structures of the microcline.