A CONTRIBUTION TO THE STUDY OF

OLDER GRANITES

IN THE NIGERIAN PRECAMBRIAN

WITH SPECIAL REFERENCE TO

THE TEGINA GRANITE

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of the degree of Doctor of Philosophy

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ABSTRACT

Rocks of the Older Granite suite occur throughout the Nigerian Precambrian. In Part I of this thesis an example, the Tegina granite, is examined in detail. In Part II the suite as a whole is described and discussed.

The petrology and structure of the Tegina granite and its envelope have been studied. The emplacement of the granite was preceded by regional metamorphism and migmatisation, and was synkinematic to the folding of the area during orogeny.

The granite is an elongate mass covering an area of 49 square miles. Structural analysis indicates its vertical emplacement under lateral pressure. This pressure was maintained during the formation of joints and secondary structures.

Three petrological units are recognised in the granite.

1) The main granite, a porphyritic biotite granite.
Granodiorite and quartz-diorite in it represent local or marginal contamination.

2) Similar rocks are developed in the zone of banded foliation. In addition there are remnant bands of granodiorite providing evidence that the 'granite' was formed as granodiorite subsequently 'granitised' with the formation of late phenocrysts of microcline microperthite.

3) The later biotite-muscovite microgranite at Karaya.
The mass is intrusive in part into regionally metamorphosed rocks of the greenschist and almandine-amphibolite facies. The original irregular roof lay near to the present erosion level, but contact metamorphic effects are slight, restricted to the local development of sillimanite hornfels in a roof zone, and boron pneumatolysis. The granite was intruded at a relatively low temperature at an estimated depth of six to eight miles below the surface.

The petrology of the Older Granite suite is described. Granitic rocks, notably a porphyritic or coarse porphyritic granite, and related migmatites, predominate. The granitic rocks include metasomatic and intrusive members. Granodiorites and quartz-diorites also occur. Other intermediate, and basic rocks, are not common. Pegmatites from a central belt are the only mineralised rocks of the suite.

Six new chemical analyses are presented.

The Precambrian of the east and far west of Nigeria is composed largely of granitic and migmatitic Older Granite rocks. A central zone is more diversified. In it metasediments are more extensively developed and include low-grade pelites and semi-pelites. A succession from an area of 2,500 square miles in this zone is given. It is conformable throughout; nor has an unconformity been demonstrated anywhere in the Precambrian on a regional scale.

The emplacement of the Older Granites is related to orogenic conditions. Field criteria indicate that all but two of the known occurrences are synkinematic. It is suggested that all the Older Granites were formed during one complex orogeny.
Granitic pebbles from metasediments pre-dating the Older Granites show that there were granitic rocks in an earlier basement.

The Older Granites are correlated with the Post-Birimian granites of West Africa. Their absolute age remains uncertain.
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INTRODUCTION

Older Granites occur throughout the Precambrian of Nigeria. But little detailed work has been done on individual masses, nor has any attempt been made to consider the suite as a whole. This thesis is concerned with the Older Granites. In Part I a detailed study of the Tegina granite and its surroundings is given, in Part II the Older Granites are considered in general.

Discussion of such aspects as the age and correlation of the Tegina granite is deferred to the second part of this thesis.

The Tegina granite falls in the 1:100,000 Tegina Sheet, mapped by the writer during the period 1955 to 1957. It was visited again during June and July 1958, and in January 1959. On these subsequent visits the area was re-mapped on a scale of 1:50,000. This map was reduced to a scale of 1:75,000 and is presented as Plate II.

Whereas much of the larger area of the Tegina Sheet is relatively inaccessible and was mapped by trekking through the villages on foot, the Tegina granite itself lies on or close to the Kaduna-Zungeru road between mileposts 16 and 38 (from Zungeru\(^1\)). Tegina is one hundred and twenty-seven miles from Kaduna by road.

The area of Plate II falls within the Kamuku Native Authority of Niger Province, Northern Nigeria, and is sparsely populated, principally

\(^1\) There are few places of reference in the area and mileposts are used in the text somewhat repetitively to indicate localities.
by members of the Hausa and Kamuli tribes. Tegina has a rainfall of some fifty inches a year, almost all of which falls in a distinct wet season between June and October. The rainfall supports an orchard savannah vegetation.

Previous work

The area was visited by Falconer during his survey of Northern Nigeria, 1904-1911 (Falconer, 1911).

The Tegina Sheet formed part of a large area of north-west Nigeria mapped, essentially on a reconnaissance basis, during the period 1927 - 1938 by Russ (1958).


Optical methods

All modal analyses are from a minimum point count of 1000, unless otherwise stated and are given in volume percentages. Optic axial angles were determined on a five-axis Leitz Universal Stage, while refractive indices were determined in sodium light, the liquids being checked on a Leitz-Jelley refractometer.
MORPHOLOGY

The Tegina granite and surrounding country varies in height from + 680 feet to 1640 feet, and falls within two drainage units; the Mariga, itself flowing appreciably to the west (see Plate III), and the Durumi, flowing in part within the envelope, to the east. Both are tributaries of the Kaduna.

The tributaries of the Mariga are ill-developed, and flow below a recent erosion surface, the latter frequently being capped by laterite. In this drainage unit exposures are often poor. In contrast to the Mariga the Durumi is an active subsequent stream, flowing essentially parallel to the strike of the rocks. Its unusual activity has resulted in exposure within it being better than the norm, with relief often being non-selective(1); and in a westward shifting of the original watershed. Until relatively recently the watershed probably lay near the mid-point of the granite, anyway as far north as milepost 33. Between mileposts 21 and 27 it now lies west of the road.

The granite itself is exposed between 850 and 1640 feet with relief features rising to a maximum of 600 feet above the plain surface. On the granite exposures are poor in the zone between mileposts 23 and 26; and along much of the western contact, notably south of milepost 20 and in the apophyse of the granite west of Kayara. Elsewhere low domes,

(1) The normal case in the Precambrian of Nigeria is for prominent relief features to be developed only on granites or related rocks, less commonly on quartzites or schists.
whalebacks and bornhardts rise from a plain surface. Irregular-shaped bornhardts occur east of Tegina, and near Kumuna and at Kagara, but whalebacks are more characteristic. These are particularly well-developed north of milepost 33, and in the eastern tongue of the granite south of Tegina. The nigmatites east of Kagara provide further good examples.

Well-jointed surfaces are not common, but give rise to occasional bouldery better-wooded slopes, as for example west of the road at milepost 36. South-east of Tegina the plain surface, originally related to the Mariua drainage system, is being rejuvenated by tributaries of the Durumi, and the drainage channels there are choked with boulders.


**STRUCTURE**

### A. The Granite

The structural elements of the Tegina granite are outlined in Table 4 and are described in the following section.

The granite covers an area of forty-nine square miles, and can be called a batholith. A batholith is defined here as a subjacent plutonic mass covering, at the outcrop, an area of at least forty square miles (cf. Daly, 1933, p.113). The granite is elongated north-south, being some twenty-three miles long and having a maximum uninterrupted width of three and a half miles. Relatively bluntly terminated in the north, the granite tapers to two points in the south.

The eastern contact is comparatively smooth, while the western is diversified by three tongue-like apophyses at Tegina, south of Babban Tunga and, notably, west of Kagara. South of milepost 35 the eastern contact can usually be located throughout to within a few yards. It is only in the south-east, to the west of Kagara and in the extreme north of the mass that, as a result of poor exposures, the location of the contact may be inaccurate.

The roof of the granite has been almost completely stripped away, but the available evidence suggests that it was irregular in section: to the north of the hamlet of Babban Tunga the granite encloses a roof
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pendant over three miles long. Adjacent to this, approximately a
quarter of a mile north of Babban Tunga, granite is directly overlain
by sillimanite hornfels at a height of 980 feet. Underneath the
pendant the height of the roof must be less. Below the syncline separ-
ating the tongue of granite from the main mass to the west of Kagara
it has been assumed to be appreciably lower still (see fig. 9, Section
CH). The highest point at which the marginal contact has been observed
is one mile north of Kumunu where it was seen at 1350 feet. There
were no indications here that this point lay near to the roof. Thus
information from the sides of the granite indicate a variation in the
height of the roof of over a thousand feet. Further, it is to be
anticipated that the roof over the central part of the mass was higher
than that at the margins.

Plate II indicates the overall concordance of the granite to
the trends of the foliation schistosity and fold axes of the surrounding
rocks.

Flow Structures

The most prevalent structural elements within the mass are
foliation and a linear parallelism of elongate xenoliths.

Foliation  In an inverted triangle, approximately located with its
apex near the median point of the granite at the parallel of milepost
36, and with its two other corners some one mile apart near the
northern boundary of the granite, foliation was either not observed,
or seen only sporadically. For the rest foliation is almost universal, if often faint. It is marked by oriented biotite flakes, normally in an open foliation, trending along the length of the granite. Only rarely is this accentuated by a platy parallelism of felspar crystals.

The foliation is normally close to vertical in attitude. It was never seen dipping at less than fifty-five degrees, rarely below seventy degrees. Over much of the mass the foliation remains constant in attitude. It does not vary towards either the margin or the roof, nor does it necessarily become more pronounced peripherally. A marginal increase in the intensity of foliation can be correlated, at any rate in part, with the composition of the metasediments adjacent to the granite. Appreciable biotite readily contaminates the granite and results in a more pronounced foliation. This is not the case where the granite abuts onto quartz-felspathic or quartzitic rocks. For example, two and a half miles ESE of Tegna, granite intrudes quartzite, and at the actual contact the foliation is barely perceptible. Only occasionally does the foliation plunge.

The foliation parallels the direction of flow at the time of the emplacement of the granite, which is thus seen to be in a vertical or near vertical direction throughout.

Elongation of xenolithic material Xenolithic material seen in the granite includes two roof pendants, large rafts, smaller rafts, and xenoliths. Much of this material is elongated in the plane of the foliation. A typical example of a large raft is that noted on the
Joints, plotted from aerial photographs

Shear Joints. Arrow indicates direction of displacement.

Fig. 1. Jointing in the Tegina granite.
whaleback immediately east of the road at milepost 23. Measuring a maximum of five foot wide by at least sixty foot long, it lies with its long axis parallel to the foliation of the surrounding granite. Foliation within the raft parallels an earlier bedding and in general lies along the length of the raft. The succession dips very steeply to the east and has a similar attitude to the foliation of the granite.

Often, as a result of recrystallisation, metasomatism, or metamorphic differentiation, little remains of original structures in the smaller rafts and xenoliths. Delicate structures may, however, be retained even in small xenoliths, Plate V, fig. 2 taken with a close-up lens, illustrates microfolding and small-scale faulting in a xenolith, where present such structures again parallel the length of the xenolith.

At a rough estimate at least seventy per cent of the xenoliths were markedly elongated. Non-elongate xenoliths may occur anywhere in the mass, but in general their occurrence is restricted to:— where rafts were observed heavily veined by granite (suggesting that such rafts were arrested in the consolidating granite during a disintegration towards the more stable elongated xenolith form);— some cases where quartzitic or granulitic rock types form xenoliths; and the inverted triangular zone at the north of the granite already noted as one of weak foliation. In this last xenoliths are less common. Where present they may be rounded or only slightly elongated (fig. 2).
The length : breadth ratio of the elongated xenoliths was commonly over five to one and was recorded up to thirty-five to one. In section the xenoliths approach a lens- or spindle-shape.

Almost everywhere the elongate xenoliths lie within the plane of the foliation, and parallel to it. The importance of this must be stressed; for although foliation planes may be secondary features superimposed after the consolidation of a mass it can scarcely, as Balk (1948, p.17) expresses it, "be assumed that .... foreign inclusions were rotated and moved into rows parallel with the foliation planes, except during, or before, the crystallisation of the rock. Thus, inclusions, oriented parallel to the planes of flow layers, are one of the surest indications that the structure is primary". By 'primary' Balk means features developed during the time of consolidation.

The shape in section of these xenoliths provides further
evidence of the direction of flow of the granite on emplacement; their elongation in plan indicates a strong lateral confining pressure at the time of such emplacement. Such pressure is assumed to have been absent or appreciably less in the zone in which flow structures were at best weakly developed near the north of the mass.

**Banding.** Banding distinguishes the zone of banded foliation from the main granite. Bands and fragments of granodiorite are enclosed by granite. Bands up to thirty feet thick have been seen, and have been traced along their length for as much as eighty yards. Normally, however, they do not exceed five feet in width. Often regular, the bands may be sharply truncated (fig. 3). Others are irregular (fig. 4), both in plan and section. The attitude of the bands is always steep, but locally variable; the irregular bands tend to bifurcate and thin upwards. The attitude of the bands is similar to that of the foliation within the granodiorite and the granite.

Large plates of microcline, characteristic of the granite, penetrate into the biotite-rich granodiorite (Plate XII, fig. 2). The contact between the two is not intrusive, the bands of granodiorite being remnants in which late-forming microcline phenocrysts have not formed. The banding is considered to represent a late flow structure, the bands themselves indicating the lengthening out of the body at that time.
Fig. 3. Shapes of granodiorite bands in the zone of banded foliation east of Tegina.
Drew from field sketches.

Fig. 4. Irregular band of granodiorite in granite. Near margin of granite 1 mile south of Tegina.
Drew from field sketch.
Pitcher and Read (1958, p. 271) have recently described another form of banding from the main Donegal granite in Ireland. There the components are granites of varying grain-size and biotite content. The contacts between the bands are again not intrusive. They consider the banding to represent a flow structure, but to be in material of different consolidation points rather than in material formed at different times as at Tegina.

**Jointing**

Nearly all of the joints observed within the Tegina granite can be referred to three genetic types, longitudinal joints, diagonal joints and cross joints. Of these the first two are common, the third comparatively rare (1). An indication of the jointing is given in fig. 1, on which joints visible on aerial photographs are plotted. In the field the joints are open or closed unmineralised cracks which may persist for considerable distances. An exception to the general unmineralised state is provided eighty yards west of the road at mile 25.6, where a diagonal joint surface is coated with plumose mica and brown calcite.

Cross joints were only occasionally observed. They lie perpendicular to the flow structures and dip at low angles, 0 to 25°.

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(1) A similar joint pattern has been described from the Nelsofruit granite in the eastern Transvaal (Visser, 1956, p. 132)
to the north. We have already seen that the flow structures represent the direction of maximum elongation of the mass at the time of its emplacement. The development of these joints results in a further lengthening of the granite, but at this later stage rupture rather than viscous flow results (Cloon, 1953, p. 266 - 7).

Two conjugate sets of diagonal joints are sometimes present, as for example east of Tegina where they strike 35° W. and 52° E. of north respectively. Foliation, trending 12° E., roughly bisects the right-angle between the two sets. More commonly, however, one of the two sets is locally suppressed. Most of these diagonal joints lie at angles of approximately forty-five degrees to the foliation, but there are some few with a trend intermediate between this and that of the cross joints.

The diagonal joints are steep surfaces, dipping at angles greater than seventy degrees. Along the majority there has been slight movement. Displacement of the order of a few inches to four feet is normal. Exceptionally, movement has been greater, as for example near the western contact two and a half miles west of milepost 35, where a horizontal displacement of twenty-five feet was noted. Some of the joint surfaces carry horizontal slickensides. Movement has been recorded in either direction along both of the joint sets. The surfaces of movement are usually marked by a thin film of streaky quartz and/or mylonitic material.
The diagonal joints represent horizontal shears along steep-sided planes. The different movements along them indicate that they are an attempt to relieve lateral pressure. They result in a further tendency for the rock mass to be elongated in the plane of the foliation.

The longitudinal joints trend parallel to the flow structures, their strike adjusting with that of the latter. All those observed lie close to vertical. Frequently these joints carry aplite veins up to one foot wide. Their origin is not fully understood. We have seen that the diagonal and cross joints are in all probability a response to lateral pressure. The longitudinal joints are at right angles to this pressure, but, commonly carrying aplite veins as they do, it seems unlikely that they can represent a compressional feature. It is thought that they may be a slightly later form of jointing than the other types, caused by contraction on cooling and subsequent rupturing along planes of easy parting. It should be stated, however, that no evidence of such an age distinction was noted in the field.

Secondary Structures

Tectonic disruption Features attributed to tectonic disruption have been recorded from several localities at or near the western contact of the mass from Tegina southwards.

Two distinct compositional forms are recognised: those associated with pegmatites, and those associated with thin granite or granodiorite veins.
Fig. 5. 'Pinch and swell' structure in conformable pegmatites. 1/2 mile east of mile 18.4.
Traced from photograph.

Fig. 6. Tectonic inclusions. Rolled up pegmatite fragments in granodiorite. 1/2 mile east of mile 18.4
Drawn from field sketch.

Features formed in pegmatites were only seen east of the road at mile 18.5. Here 'pinch and swell' structures were found in conformable pegmatite dykes (see fig. 5.). The dykes do not exceed nine inches wide. On an outcrop to the east of this several isolated fragments of pegmatite were seen. Relic structures within the irregularly-shaped pegmatite 'inclusions' suggest that they represent fragments of an original pegmatite which has been broken up and suffered considerable rotation (fig. 6.).

Thin granite or granodiorite veins, intruding earlier quartz-diorite or meta-sedimentary rafts, were seen in various stages of
disruption, notably to the east of Tegina itself. All the resulting forms are elongated parallel to the foliation or schistosity of the enclosing rock. None of the veins exceed three inches in width. Plate IV, fig. 2 illustrates the necking down of a continuous vein. Rarely do separated 'inclusions' form, more commonly lens-shaped masses are joined by thin threads of the vein material. When complete separation of these masses has occurred it is along diagonal shears (see fig. 7).

Fig. 7. Incipient tectonic disruption of granite veins in quartz-diorite. 1 mile east of Tegina. Drawn from field sketch.

A completely separated inclusion was, however, observed a quarter of a mile east of mile 18.4. Here a sheared 'enclave' of granite lies...
within foliated quartz-diorite (fig. 8). On first examination the granite was regarded as a normal xenolith. It was subsequently established from a nearby outcrop that the granite intrudes the quartz-diorite. Re-examination indicated that the 'enclave' was a tectonic inclusion.

All the above features are regarded as being part of the same process. In the literature they are among the various phenomena normally loosely grouped under the heading of boudinage (see for example Ramsberg, 1955, p.512). The generally accepted raison d'être for boudinage is a difference in competency between the boudin layer and the adjacent rocks when subjected to compression; the more competent boudin layer behaving differently to the relatively incompetent surrounding rocks, resulting in a stretching in one form or another, or, under more extreme conditions, rupture.

The writer follows Rast (1956, p.401) in considering that the term boudinage should be restricted to those barrel-shaped bodies characterised by tension between the boudins, favouring the terms tectonic disruption and tectonic inclusion for features such as the above, in which compression is all-important. In the features described the long axes lie in the strike direction, the extension being normal to the direction of pressure\(^{(1)}\).

The types of tectonic disruption noted above must have formed at

\(^{(1)}\) Forms have also been described elsewhere, still with their extension normal to the direction of pressure, but with their long axes lying in the dip direction (Coe, 1959, p.200).
the time of or subsequent to the emplacement of the granite and pegmatite veins. Their presence provides an indication of lateral compression applied subsequent to the emplacement of the main mass of the granite.

**Other secondary structures**  Much of the shearing seen is associated with diagonal joints and forms a distinct pattern that has already been noted. Locally shearing of irregular attitude has also been seen.

Unusual shear planes were seen near the western margin of the granite east of Tegina. The strike of these planes was variable, one of them being followed through one hundred and fifty degrees. Associated with them were large blown of quartz, horizontally slickensided. Foliation, too, was variable. The rock appeared to have been locally 'shoved' in several direction, with associated shearing, in a plastic or semi-plastic condition.

In a zone approximately forty yards wide some one hundred and fifty yards in from the eastern contact southwards from Tegina the rock is intensely foliated. Pronounced foliae of biotite separate off irregular-shaped angen of felspar (Plate XII, fig. 3). Under the microscope the texture of the quartz is cataclastic. It has been granulated, recrystallised and is full of strain shadows. The cataclastic zone can be traced south into a mylonitic quartzite. This secondary foliation parallels the normal foliation. So does the secondary foliation associated with disrupted pegmatite east of the road at mile 12.5.
B. The Envelope

The Tegina granite is emplaced within folded metamorphic rocks.

To the west and north-west of Kagara only faint nebulitic structures were recorded in the migmatites. Near the granite two and a half miles west of Kagara the migmatitic rocks are locally highly contorted. Randomly-oriented shearing abounds, and thin irregular-shaped offshoots of granodiorite occur squeezed into the migmatite. The country rock appears to have been in a plastic state at the time of emplacement of the granite. Elsewhere structures are more regular, and a number of fold axes were noted. These are plotted on Plate II.

Axial planes of these folds stand vertically. The anticline west of Tegina probably plunges north towards the granite, while the nose of the most easterly anticline shown on Plate II plunges south. Elsewhere the axes normally do not plunge.

Around the north of the granite the rocks dip at moderate angles. On several outcrops within this zone the foliation was noted plunging away from the granite, i.e. northwards. Elsewhere the foliation or schistosity is steep or vertical. South of Tegina nearly all the rocks examined stand vertically. In general then there is a tightening up of structure from north to south. This is reflected in the shape of the granite itself, bluntly terminated in the north, tapering to the south.
Cataclastic structure, and tectonic inclusions and related phenomena noted in the granite itself are reflected in the surrounding rocks. Adjacent to the granite east of the road intersection at mile 21 angular fragments of calc-silicate granulite, attributed to tectonic disruption, are included in quartz-mica schist.

The cataclastic zone in the south-east of the granite is continued south in a mylonitic quartzite (see Plate XI, figs. 1 & 2), a close-jointed brittle, streaky, grey rock, in which drag-folding is common (Plate IV, fig. 1). The folding indicated movement in which the western side has moved north relative to the eastern. Another cataclastic zone, again parallel with the strike, was noted further east. This zone, some fifty yards east of the granite and extending to the south of it, is marked by knobly mica schist cropping out along a ridge. Displaying drag-folds with a similar sense to those in the quartzite, the rock was seen under the microscope to be drawn out to a phyllicitic texture (see microphotograph, Plate IV, fig. 3).

The origin of the quartzite described above is of interest. In the discussion of a recent paper by Recce (1959), Davies and others (op cit., p. 77 et seq.), have questioned the status of certain Precambrian quartzites in Uganda. There many of the quartzites originally though to have had a sedimentary origin were now regarded as later quartz bodies formed by silification, often along shear zones. The quartzite south of the Tegina granite lies on a shear zone; it
does not contain the characteristic accessory assemblage (sillimanite-
garnet-hematite) of the quartzites from the Kusheriki Sheet, considered
to be of sedimentary origin. It may also be a silicified shear zone.
Fig. 9. Sections from Plate II, the Tesina batholith and its surroundings.
PETROLOGY

4. Of the envelope

The rocks of the envelope are all metamorphosed. Those grouped (see Plate II) as augen-gneiss, banded gneiss and migmatite, and anatectic migmatite, represent a process, metamorphism, rather than a stratigraphical unit. This process is outlined in their description.

The other units mapped are stratigraphical. In the succession established for the south-western half of 1:250,000 Sheet No. 31 the majority of them (mullizanite hornfels, talo-carbonate and chlorite schist, amphibolite, green schist, quartz-mica schist and quartzite, calc-silicate granulite, and undifferentiated schist) fall within the Heterogeneous series of the Schist group. The meta-arkosic rocks belong to the Meta-arkosic series of the Banded group. The occurrence of these rock types is also noted in the following section.

The metasomatic rocks

The rocks of the infrastructure are a complex group, and include such types as augen gneiss, banded gneiss and migmatite, anatectic migmatite and granite.
The writer would define a nigratite as a two-component rock composed of a metamorphic host into which later acid material had been squeezed, the two components being characteristically intimately associated. All the above rocks are nigratitic, for to them have been added pegmatitic, felspathic or, rarely in this area, granitic material. A further process recognized in some of these rocks is metahblastesis, the recrystallization and growth of quartz and felspar crystals.

In the field distinction was made between those rocks in which the structural features of the original crystalline rocks were preserved or partially preserved; and those in which such structures were at best faint, the rocks themselves being more granite-like in composition. For these two classes of rocks Jung and Roques in 1939 used the terms embrechites and anatexites respectively, see Roques, Lapadu-Margues, and Bradshaw (1954). However, all the rock types are gradational, and no sub-division could be mapped. But in broad terms the rocks east of the road east and north-east of Kagara are anatexites, the remainder embrechites. In equally broad terms the nigratites to the east of the granite if followed along the strike north-north-eastwards from the parallel of milestone 17 contain successively more and more introduced material. Elsewhere variations are less coherent.
Although the magnetitic rocks are in contact with the granite at its northern end and in part to the west of it, they do not represent an aureole to it.

In outline we have thus a gradational series of magnetitic rocks to which pegmatitic and felspathic material has been added. With increasing metasomatism the resultant rock approaches closer to granite in composition and retains fainter traces of original structures. Ultimately the resulting rock may be difficult to distinguish from an intrusive granite in hand specimen.

The processes involved are complex in detail; some examples follow.

Plate VI, fig. 2 illustrates a metasomatized banded gneiss. Conformable felspathic offshoots run from a slightly cross-cutting pegmatite and permeate much of the rock. The potash felspar of both rock and pegmatite is microcline. Note the undisturbed dark-coloured metabasite band. The ferromagnesians in it are biotite, with appreciable sphene and epidote. Normally such basic bands are amphibolitic. One hundred yards west of the road at mile 22.8 such an amphibolitic band has been broken up into pod-shaped masses; fig. 10 shows the breakdown of metabasite into agmatitic fragments.
Fig. 10. Pegmatitic meta-basite in pegmatite. North slopes of Dutaia Uregi (see Plate III). Traced from photograph.

Fig. 11. Aplite and pegmatite veins in foliated rocks 2 miles east of Egozara. Traced from photograph.

With increasing foliation these rocks may grade to porphyroblastic granitic gneisses\(^\text{(1)}\). There is a good example of this in a tributary of the E. Esea east of milepost 28, where increasing foliation results in such a rock. In it porphyroblasts of felspar (~5 mm.) are set in a fine-grained rock in which foliae of biotite are prominent. Pegmatitic blobs are common, and basic ‘saxolites’ were noted. A modal analysis of this rock is very similar in mode to the Tegina.

\(^{(1)}\) While favouring the use of the term gneiss in structure where applicable, the writer feels that the term gneiss, unqualified, should be used sparingly. Many so-called granite gneisses could more appropriately be styled foliated granites, others migmatites.
granite (see table 7).

The meta-arkoses

These rocks are poorly exposed north of the granite west of Mall names, and east of the migmatitic rocks southwards from the parallel of Kuma. They are never in contact with the granite. Intercalated with the arkose rocks are amphibolites, which are usually banded and often partly biotitised, and, rarely, granulitic quartzites.

The meta-arkoses are composed of quartz, microcline, and oligoclase, with small amounts of biotite and muscovite. With increase in mica content the rocks grade to quartz-felsparitic gneisses. The rocks are fine to medium-grained and light in colour. Occasional coarse inlets of quartz or microcline result from metasomatism.

Green schist

Outcrops of actinolite schist were recorded on the north slopes of the hill half a mile south-east of Kagal. The rock is green, composed essentially of elongate crystals of actinolite, and displays a poor schistosity.

Under the microscope the lath-like actinolite crystals normally do not exceed 5 mm. in length and are commonly in divergent clusters. Accessories are interstitial chlorite, and magnetite in ill-formed granites.

It was hoped that this rock would provide a useful marker
horison, but it could be traced only over a width of fifteen feet and along the strike for thirty yards.

**Magnesian schists**

Chlorite schists and talc-magnesite schists are associated in a narrow elongate body one and a half miles long north-east of Kumnu. A further small occurrence of talc-carbonate schist was noted in the River Kharuma south-west of Tungan Bako.

Near the northern extremity of the mass at Kumnu an inclusion of chloritic schist in talc schist was interpreted as a xenolith. The chlorite schists are green to dark-green fine-grained rocks characterised by porphyroblastic octahedra of magnetite up to 1 cm. in diameter. In thin section these schists are seen to be composed almost entirely of minute laths of chlorite (less than 0.5 mm. in length), pleochroic from colourless to green and with approximate refractive indices of *n*α = 1.565, *n*γ = 1.575 (see Plate XIV, fig. 4). Magnetite occurs both as small irregularly-shaped crystals and as larger porphyroblasts of granular appearance.

The talc-carbonate schists are grey, sometimes yellowish soapy schists, with a pronounced schistosity. The principal component of these schists is talc, but they also contain a varying percentage of carbonate, principally magnesite. One slide contained ninety per cent of magnesite, with *n*α = 1.522, *n*γ = 1.720, but this is exceptional.

The talc schists contain a few small segregations of dense greenish-black serpentine. In thin section a dense colourless
antigoritic serpentine displays a fibro-lamellar structure, and is shot through with secondary carbonate and associated magnesite (Plate XIV, fig. 3). In hand specimen occasional thin cross-fibre veinlets of chrysotile traverse the serpentine.

**Quartzites, quartz-mica schists**

Micaeous quartzites and quartz-mica schists, with intercalated mica schists, were mapped at the south of the granite and extend north along the eastern contact as far as Kummu (see Plate II). Similar rocks may also occur in the undifferentiated schists, as for example east of the road at Mile 33.5 and east of the Kantagora road junction; and as xenoliths in the granite.

The quartzites normally contain up to ten per cent of muscovite. Less commonly biotite, pleochroic with X brownish green, Y and Z olive green, may be present. Tourmaline is a frequent accessory and occasionally may rate as a principal constituent (JF 320). The cataclastic zones in these rocks, principally the mylonitic quartzite south of the granite and the phyllemic quartz-mica schist to the east, and the structures within them, have already been noted. In undisturbed rock oriented flakes of mica lie in a granoblastic aggregate of quartz.

The quartz-mica schists contain two micas, the mineral assemblage being either biotite-muscovite-quartz (-alkite) or muscovite-biotite-quartz (-alkite). The mica schists have a similar mineralogy. In the phyllemic schist, however, the micas are muscovite and chlorite. In this rock bands rich in quartz, chlorite
and quartz, and muscovite, with the muscovite bands often marking surfaces of slip, alternate (see Plate IV, fig. 3). The chlorite forms crystals up to 3 mm. long, weakly pleochroic from pale yellow green to green and has refractive indices of \( \alpha = 1.573, \beta = 1.595. \) Elongation of minerals is often intense and even accessory ilmenite may be drawn out to thread-like forms. Other accessories include apatite, crystals of green tourmaline and several small round garnets.

The quartztitic rocks are associated north-west of Kuma. Cavities in the rock contain pyramidal quartz and chalcedony, also small amounts of both magnetite and hematite. In thin section the chalcedony is typically spherulitic.

**Amphibolites**

The occurrence of the amphibolitic rocks can be seen on Plate II(1). They are in contact with the granite near Tagina, and north and south of Kagara. The amphibolites are green or blue fine-grained rocks, and are usually banded or gneissose.

In thin section the rocks have a lepidoblastic texture. The characteristic mineral assemblage is hornblende-quartz-(oligoclase- plagioclase-iron ore) with the hornblende commonly partially altered to chlorite. The colour indices of the amphibolites are high (see table 5). Plagioclase is always subordinate in amount to quartz and, as it is

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(1) **Amphibolitic rocks** are also present as xenoliths in the granite, as bands, lenses, etc. in magnetitic rocks, and as intercalations in the meta-arkosic rocks.
rarely twinned, may be difficult to distinguish from it. The
hornblende of JF 253 had an e 25°, N α = 1.631, N γ = 1.660, and was
pleochroic as follows: I greenish yellow < Y bluish green
< Z greenish blue. Refractive indices of plagioclase (JF 253) were
N α = 1.534, N γ = 1.538, indicating a composition of Ab56.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hornblende and</td>
<td>62</td>
<td>78</td>
<td>36</td>
</tr>
<tr>
<td>chlorite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epidote</td>
<td>-</td>
<td>Accessory</td>
<td>56</td>
</tr>
<tr>
<td>Quartz</td>
<td>25</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>10</td>
<td>Accessory</td>
<td>Accessory</td>
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<tr>
<td>Sphene</td>
<td>-</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Accessories</td>
<td>Iron ore</td>
<td>Plagioclase</td>
<td>Epidote, Iron ore</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plagioclase</td>
<td>Iron ore</td>
</tr>
</tbody>
</table>

Table 5. Modes of three amphibolitic rocks from the Kagara area.

1. Amphibolite (JF 253). Hill half a mile south-east of Kagara.
3. Epidote-amphibolite (JF 276). Hill west of milestone 34.

Epidote-amphibolite was noted on the low hill west of milestone 34. Composed largely of granular epidote and hornblende the rock
contains oligoclase as an accessory.

**The sillimanite-bearing rocks**

At several localities bordering the granite in the large roof-
pendant near the road between milestones 30 and 26, and nearby, at the
contact of the granite tongue south of Habban Tunga, micaceous
garnet-sillimanite hornfelses occur. A quarter of a mile north of
Babban Tunga the hornfels directly overlies granite. A rock similar to the above was found near the granite contact east of the road at milepost 21.

When fresh garnet porphyroblasts and sillimanite laths can be seen in a grey-blue rock which is variable in grain size. These rocks weather brick-red.

In thin section the rock has a granoblastic texture. Modal amounts of the minerals present vary, as shown below (in volume percentages):

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>30 - 55%</td>
</tr>
<tr>
<td>Muscovite</td>
<td>12 - 29%</td>
</tr>
<tr>
<td>Biotite</td>
<td>5 - 20%</td>
</tr>
<tr>
<td>Sillimanite</td>
<td>5 - 20%</td>
</tr>
<tr>
<td>Spessartite</td>
<td>Accessory amounts - 10%</td>
</tr>
</tbody>
</table>

Accessories present were plagioclase, iron ore, zircon and tourmaline.

Muscovite and biotite are normally present in equal amounts.
The spessartite crystals are corroded and carry granules of iron ore.
The biotite is strongly pleochroic with a pale yellowish-brown
< Y = 2 reddish-brown, and has refractive indices of N α = 1.553,
N Y = 1.590. The sillimanite occurs in small, often minute, fibrolites
lying in the quartz and muscovite. There are also a few larger
prismatic crystals, typically bent and having stress-fractures, with
refractive indices of N α = 1.656, N Y = 1.679. The smaller
fibrolites frequently coalesce in a grey or brown mass (see Plate
XIV, fig. 2).

Sillimanite also occurs in microscopic amounts in muscovite-
bistite-quartz schist in the slice of country rock lying in the granite east of Tegina.

Miscellaneous

Calcsilicate granulite

Granulitic rocks have been recorded from several localities near the western contact between mileposts 33 and 21, both within the granite as xenoliths, and outside it. Apart from occasional float occurrence of these rocks outside the granite is restricted to part of a disrupted vein one mile south of Tegina, and an isolated pytically folded outcrop some one mile west of milepost 26 (see fig. 12).

![Diagram](image)

**Fig. 12.** Pytically folded calcsilicate granulite, 1 mile west of milepost 26. Drawn from field sketch.

These rocks are light-coloured (gray, brown or reddish), and are usually banded. Grossular garnet is characteristic in this, a

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(a) The term granulite is used texturally, and does not denote metamorphic grade.
quartz-rich calcareous assemblage. Essential minerals are quartz, grossularite, hornblende, diopside and an epidote, with chlorite, calcite, calcic plagioclase, iron ore and sphene as accessories. The texture of these rocks is granoblastic.

The different bands show considerable variation in the modal amounts of the minerals present (Plate IV, fig. 4). The grossular garnet is pale brown, may have an open sieve structure and has a refractive index of 1.744.

Diopside-hornblende-biotite rock: An exposure of the above, a greenish-black foliated rock with a brown patina, was seen three-eighths of a mile south of Tegina. The node of specimen JV.303 (volume per cent) is diopside 34, biotite 30, hornblende 30, sphene 4, with two per cent of accessory quartz, calcite, clinohochrome and magnetite.

Tourmaline: Black tourmaline occurs in quartz-tourmaline veins, grading to tourmaline rock; in accessory amounts in the sillimanite hornfels; and in irregular patches of the chlorite schist as six-sided prismatic crystals up to five centimetres in length, studded with octahedra of magnetite. (Tourmaline is also known as occasional stringers in quartz veins in the granite). In thin section the tourmaline is grey-blue to green. Colour zoning is common in the larger crystals. The tourmaline crystals in the chlorite schist are late growths, impinging on the rock schistosity (see micro-photograph, Plate XIV, fig. 4). This tourmaline, with $N_c = 1.634$, $N_o = 1.662$
has a composition of sixty-eight per cent of the scharlitz molecule, thirty-two per cent of the dravite molecule (Winchell, 1951, Vol. II, p. 466).

**Contact Metamorphism**

Contact metamorphic effects are slight, restricted to the localized development of sillimanite hornfels and the more ubiquitous formation of tourmaline.

The sillimanite hornfelses have a mineral assemblage of quartz-biotite-sillimanite-spessartite, and are semi-pelitic rocks metamorphosed to the hornblende hornfels facies. With the exception of a small outcrop south of Tegina all these hornfelses occur between mileposts 26 and 29 near either the western margin of the granite or the roof pendant within it. They represent a roof zone to the granite.

Sillimanite was also noted, in microscopic amounts, adjacent to the granite in the slice of country rock east of Tegina. Here the occurrence is in quartz-biotite-muscovite schists, frequently deformed. Tuzer (1955, p. 312) has described similar rocks along the contact of the Donegal granite at Glen in Ireland. There he considered that plastic shearing had played quite as important a part as the thermal factor in the formation of sillimanite. A like explanation is suggested for the above sillimanite.

Tourmaline is found frequently in rocks near the granite, for example in the muscovite quartzites and the sillimanite hornfels.
Its most unusual occurrence is as large late-forming crystals in the ultrabasic chlorite schists. The tourmaline has formed from boron-rich pneumatolytic emanations. Quartz-tourmaline veins, related to the granite, are common in the vicinity. Harker (1950, p. 117) considers that such veins mark the channels of supply for the tourmaline in the rocks. This would seem to be the case at Tagima.

**Regional metamorphism**

Use has been made of the facies concept of metamorphism in an attempt to correlate the assemblages described and to gain an appreciation of the conditions under which the rocks were metamorphosed.

Some characteristic mineral assemblages are shown in Table 6.

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(1) *A metamorphic facies includes rocks, irrespective of composition, which have formed in metamorphism under specific physical conditions, notably of temperature and pressure. The concept was introduced in 1915 by Eskola (1920). Further data has resulted in considerable modification to the original classification (see for example Tilley, 1924; Turner, 1945; Turner and Verhoogen, 1951). Turner has recently stressed the difference between regional and contact metamorphism in a further modification (Kyte, Turner and Verhoogen, 1958). It is this latest classification that is followed here.*
Green schist facies  The assemblage muscovite-chlorite-quartz (1) belongs to the quartz-albite-muscovite-chlorite sub-facies of Turner (Eyfe, Turner and Verhoogen, 1958, p.201). It is found only in the phyllonitite rocks south-east of the granite and probably represents retrograde kinetic metamorphism. Retrograde metamorphic changes are in general sporadic and often related to hydrothermal changes (Schwartz and Todd, 1941, p.182), but phyllonitisation has been recorded related to structural features (Haasf, 1931, p.8). All other rocks of the quartzite and quartz-mica schists (muscovite-quartzite, quartz-biotite-muscovite (2) schist, biotite-muscovite-quartz schist) can be referred to the quartz-albite-biotite sub-facies. It has already been noted that the quartzites south of the granite may represent a silicified shear. The other rocks represent a sedimentary sequence.
The actinolite-(chlorite) schist (3) is a typical green schist and is probably a metamorphosed basic dyke.

The assemblages (4) (5) and (6) are metamorphosed ultrabasic intrusives, formed from the breakdown of olivine-rich rocks under conditions in which silica and carbon dioxide are present in aqueous solution. Magnesite and magnetite form as a result of the liberation of magnesium and iron oxide during the formation of the talc (or antigorite) schist. Magnesian serpentine contains thirteen percent of water, talc less than five. Bowen and Tuttle (1949) have shown that in the system MgO-SiO₂ - H₂O talc is stable to greater temperatures than serpentine. The limited occurrence of serpentine is considered to reflect temperature conditions rather than a restricted amount of aqueous solution at the time of metamorphism.

Almandine-amphibolite facies All other rocks are ascribed to the almandine-amphibolite facies, and fall into the steatolite-quartz sub-facies.

(7) is the typical association of the meta-arkosic rocks.

(8). These granulitic rocks have been found not only near the western margin of the Regina granite, but also as xenoliths in the granite, and further east, on the Alama Sheet, as thin intercalations in mica schist. They are thought to represent metamorphosed calcareous sandy sediments. It should be noted, however, that King and de Swardt (1949, p.27), describing similar diopside-garnet bearing rocks from the Igbara contact zone of the Osi granite in Ilorin Province
related them to an early front process of granitisation. (9) is also a calcareous assemblage, in which the calcic plagioclase is unusual (cf. Pyne, Turner and Verhoogen, 1958, p.229). (10) and (11) are amphibolitic assemblages. No definite criteria could be established as to whether these amphibolites were of igneous or sedimentary origin.

B. The Granite

Field occurrence

Three units have been recognised in the granite. These are:

(1) The Main granite

(ii) The zone of banded foliation

(iii) The Karaya microgranite

(1) the major unit is the Main granite, a porphyritic foliated biotite granite. Phenocrysts of microcline are set in a fine- or medium-grained rock composed of biotite, plagioclase and quartz. The potash felspar may be pale cream or pink in colour, as for example near Kummu and in the south-eastern tip of the granite, but it is normally white in colour. Carlsbad twinning can often be seen along the length of the larger microcline crystals. Jet black biotite is normally the only ferromagnesian mineral present.

This unit also includes granodiorite and, rarely, quartz-
diorite as marginal or local variations. These variations are gradational to granite and do not represent separate intrusions. As an example, a quarter of a mile west of the Karaya microgranite
the granite grades to granodiorite with increase in biotite content, decrease in potash felspar. Quartz-diorite is of very localised occurrence. An example is shown in fig. 13. There a marginal granodiorite encloses a large xenolith of calc-silicate granulite. Quartz-diorite, rich in garnet, hornblende and biotite, forms a contaminated border in part. Another illustration of this rock is shown as Plate XIII, fig. 3.

![Fig. 13. Garnetised border at contact of calc-silicate granulite xenolith and granodiorite. West of the road at mile 25.7. Drawn from field sketch.](image)

(ii) A zone of banded foliation has been traced along the western margin of the granite in a strip never more than a mile wide between mileposts 24 and 18.

This zone contains the same components as the main granite. But in addition it is characterised by bands of granodiorite in the granite. The size and shape of these bands has already been described (see p. 12). Irregular banding is shown in fig. 4; shapes of granodiorite bands in fig. 3. A contact between granodiorite
and granite is figured in Plate XII, fig. 2. This contact is not intrusive. Porphyritic felspars from the granite penetrate into the granodiorite, and in the field it was plain that the granodiorite represented remnant bands in which these felspars had not formed. The significance of this banding will be examined later.

![Diagram](image)

**Fig. 14.** Granite dyke cutting granodiorite 1 mile east of Tegna. Drawn from field sketch.

Other features recorded from this zone included occasional occurrences of quartz-diorite; and an unusual late granite cutting granodiorite near the margin of the granite east of Tegna (fig. 14). The quartz-diorite is a dark, medium-grained foliated rock (see also Plate VI, fig. 1). Granite is intrusive into this rock along an irregular contact half a mile south of Tegna (fig. 15), and a similar relationship was established a quarter of a mile east of the road at mile 18.5. The quartz-diorite is an early, separate intrusion.
(iii) The Karaya microgranite lies near the north-eastern margin of the granite west of milepost 37. It is one and a third miles long and has a maximum width of 600 feet. The rock is a biotite-muscovite microgranite of very uniform texture. In contrast to the other units it does not contain xenoliths of country rock, but occasional micaceous schlieren were noted.

Part of the eastern contact of the microgranite with the granite is sketched in fig. 16. The microgranite is intrusive into the granite, the contact showing no chilling.
Contact phenomena  The granite is in contact with metasomatic rocks or members of the Heterogeneous schist series, and is overlain by hornfels in the roof pendant at Bobban Tunga. With exceptions in the extreme north, west of Kagara and in the south-west, the contact can usually be located to within a few yards. The contact itself was, however, only seen at three localities. All of these are in the southern half of the granite, and in all of them granite intrudes quartzitic rocks.

At the south-eastern extremity of the granite, granodiorite of normal texture locks around the prominent sylmantic quartzite; half a mile east of mile 17.5 granite interfingers with muscovite quartzite. Near the contact the granite is not porphyritic, two
and a half miles ESE. of Tegna the contact dips 61° to the east. Adjacent to the contact the granite contains occasional coarser felspathic knots. At none of these localities was there a chill zone.

Mineralogy

The mineral association of the granite (and granodiorite) is microcline microperthite-alganelase-quarts-biotite-micropegmatite. Hornblende is present only in the quartz-diorite, from which micropegmatite may be absent. Primary muscovite occurs in the Karaya microgranite. The accessories apatite, magnetite and ilmenite, sphenite, orthite and siron, are present in all these rocks, but are more abundant in the granodiorites and quartz-diorites. This is particularly the case with sphenite and apatite.

Modal analyses of typical rocks are shown in Table 7. The following description of the various minerals refers to the granite, and the (contaminated) granodiorite and quartz-diorite of the main granite and zone of banded foliation. The mineralogy of the early quartz-diorite, and the microgranite, are described afterwards.

Microcline microperthite occurs in the granite as plates of irregular shape with a diameter of up to 6mm. Commonly the larger plates are 2 to 3mm. across.

'Cross-hatching', the result of spindle-shaped polysynthetic twinning on the albite and pericline laws, is ubiquitous in the microcline. Carlsbad twinning was seen occasionally.
<table>
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<tr>
<th>JF. Nos.</th>
<th>Granite</th>
<th>Granodiorite</th>
<th>Quartz-Diorite</th>
<th>Microgranite</th>
<th>Granitic Gneiss</th>
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<td>991 1007</td>
<td>914 899 943</td>
<td>966 944</td>
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<td>2 1 32 31</td>
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<td>JF. 91.4</td>
<td>JF. 899 JF. 943</td>
<td>JF. 966 JF. 944</td>
<td>JF. 912 JF. 967</td>
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</tbody>
</table>

Table 7. Modal analyses of rocks from the Tegina area

JF. 285  Granite, Summit of Kagara hill.
JF. 990  Granite, Near margin of granite east of Tegina.
JF. 894  Granite, 2 statute miles west of milepost 35.
JF. 991  Granodiorite, Near margin of granite east of Tegina.
JF. 1007 Granodiorite, 1 statute mile SSE of Tegina.
JF. 914  Early quartz-diorite, 1/2 mile east of mile 18.5.
JF. 899  Quartz-diorite, contaminated marginal rock, West of the road, mile 15.8.
JF. 943  Quartz-diorite, contaminated rock, 1/4 mile west of the Karaya microgranite.
JF. 966  Microgranite, Karaya. Analysed specimen.
JF. 944  Microgranite, Karaya.
JF. 912  Granite-gneiss, 1\(\frac{2}{3}\) miles northwest of Babban Tunga.
JF. 967  Granitic gneiss, 2\(\frac{1}{4}\) mile east of mile 36.3. Analysed specimen.

(1) A = apatite, C = calcite, Cl = clinozoisite, E = epidote, M = iron ore, O = orthite, S = sphene, Z = zircon.

(2) Approximate modes.
Microcline encloses grains of quartz, biotite, and, more frequently, plagioclase. The microcline is perthitic, and three types of microperthitic intergrowth were noted. In these, acid plagioclase occurs as irregular blebs sharing a common orientation with unenclosed plagioclase marginal to the microcline; as uneven sericitised blebs usually slightly elongated parallel to (010); and as thin clear rods, ~1mm long, of similar orientation. The first of these intergrowths is replacement type, the other two involve exsolution. Only the second type is common. This is the patch type of perthite of Alling (1932, p.61). The plagioclase component never accounts for more than twenty per cent of a perthitic crystal. The host potash felspar may be clear, but parallel to one or both of the major twinning directions it is often turbid. This may indicate a further cryptoperthitic intergrowth.

The optic axial angle of the microcline varied from 75° to 80° (IF. 990, 1000, 894). Refractive indices measured (IF. 990) were: N δ = 1.520, N γ = 1.526. Hewlett (1959) has recently shown that small amounts of Ca, Ba and Sr, the degree of unmixing, and the Si/Al order—disorder relation, may all affect the optical properties of potash felspars. But from the earlier tables of Tuttle (1952, p.557, 559) the composition indicated from the above data is microcline containing 20 - 25 per cent of albite.

Plagioclase occurs in tablets with irregular margins. Many of these are ~ 1mm long, and the range in size is normally between .5 and 2.5mm.
The plagioclase is usually heavily sericitised, although the margins and patches within the crystals are frequently clear. Flakes and larger pieces of secondary muscovite have also developed. Saussuritisation, with the development of secondary epidote or clinozoisite and calcite, is occasionally associated with the sericitisation (see for example, IF. 418).

Twinning on the albite law is universal, on the Carlsbad law less common. The plagioclases are slightly zoned. The composition is invariably in the oligoclase range. Refractive index values for the granite (IF. 990), measured on (010) flakes, were

\[ N_\alpha \text{(minimum)} = 1.534, \quad N_\gamma \text{(maximum)} = 1.544, \]
indicating a composition of Ab_{87-77} (Tsuboi, 1923). Granodiorites gave similar figures. The oligoclase of the quartz-diorite (IF. 899) was more basic. With \[ N_\alpha \text{(minimum)} = 1.539, \quad N_\gamma \text{(maximum)} = 1.546. \] From this a composition of Ab_{79-72} was indicated.

The quartz grains in these rocks are often clustered. No grains exceeded 1.5 mm in diameter. Quartz also occurs intergrown with felspar in micropegmatite, and as very small crystals (usually > .1 mm) associated with the micropegmatite.

Biotite forms irregular tabular crystals, of less than 1 mm in length. In the granites and granodiorites the pleochroism of the biotite is X straw yellow, Y = Z dark brown, almost opaque. In one example of quartz-diorite at the margin of the granite (IF. 899),
I was yellow, Y and Z a lighter richer brown. Inclusions of zircon surrounded by pleochroic haloes, are more common in the granodiorite and quartz-diorites. Refractive indices (JF. 990) were \( N_\alpha = 1.564 \), \( N_\gamma = 1.618 \). Difficulty was experienced in determining the exact 2V of the biotite. Rotation in the optic axial plane resulted in total extinction for up to 15° of arc (corrected). The 2V must lie between 0 and 15°.

Biotite alters to chlorite, and in the change magnetite is liberated. The chlorite has grey-green polarisation colours, and is pleochroic, with X pale yellow, Y and Z rich green. The alteration is often in zones parallel to the (001) cleavage.

The myrmekite often envelopes microcline microperthite. The felspar in this material may be clear or turbid. Crystals are up to 0.4 mm in diameter, and in the larger ones the intergrown quartz is often vermicular.

Hornblende is present only in (some of) the quartz-diorites. It forms plates of up to 2.5 mm, diameter. It is pleochroic, with X yellow, and Y and Z greenish-blue in colour. Properties of hornblende from JF. 899 were extinction \( x^Z = 13^\circ \); 2V \( \alpha = 67^\circ \); and refractive indices of \( N_\alpha = 1.640 \), \( N_\gamma = 1.673 \). Hornblende from this rock is shown enclosing garnet, appearing black under crossed nicols, in Plate XIII, fig. 3.

**Accessory minerals** The most characteristic of these
is orthite. Often the orthite forms singly or doubly terminated pinacoidal crystals, with idiomorphic outlines or faces. Crystals with a length of up to 2.5 mm, have been seen. The orthite is invariably either partially or wholly metamict. Still-ordered fragments, orange-brown to yellow-brown in colour and being non-pleochroic, remain in a pale yellow, or rarely grey, base of isotropic material. The orthite often shows zonal growth. Granules or rims of epidote occur in some of the Orthite crystals (see Plate XV, fig. 2). In one case (JF. 990), twinning on (100) continued from a core of orthite through a rim of epidote. Extinction measured (JF. 990) X was 37°. 2V was in the range 1.73 – 1.745, but because of the metamict state it did not prove possible to establish the optical axial angle or exact refractive indices of this mineral.

The other accessories, sphene, apatite, iron ore, and zircon are invariably more abundant in the grano-diorites and quartz-diorites than in the granites. For example sphene forms small euhedral neutral-coloured fragments < .2 mm, in the granite of JF. 990; and crystals up to 1.5 mm, across in the adjoining granodiorite (JF. 991), where it is pleochroic from grey-brown to grey.

The zircon crystals are usually roughly square or prismatic in section, and neutral-coloured. Zircons examined from concentrates of the granite (JF. 990) and granodiorite (JF. 991) were idiomorphic
to sub-idiomorphic. Their size did not exceed .25 mm., and their length: breadth ratio ranged from 3 to 5:1. The zircons are clear, and occasionally carry minute black inclusions. Their shape provides corroborative evidence of the intrusive nature of the granite (Feldervaart, 1956.)

Anatite crystals are usually all otriomorphic, but they may be larger, up to .5 mm. in length.

Both magnetite and ilmenite are present in these rocks.

A distinct order of crystallisation is apparent in the essential constituents of the granitic rocks of the Tegina granite. In outline late phenocrysts of microcline microperthite often include plagioclase, quartz or biotite crystals. The former have plainly formed after the latter. Very fine-grained quartz and felspar, with myrmekite, are interstitial to, or replace, the microcline, and are the latest-forming minerals. The texture of the rock is allotriomorphic.

It is instructive to compare the mineralogy and texture of the Tegina granite with other porphyroblastic granitic rocks from the area, of similar bulk composition, thought to have formed in place. These metasomatic rocks can be distinguished by any or all of the following: locally more abundant accessories, with magnetite often idiomorphic; less range in the size of the grains, notably absent are the very fine-grained quartz and felspar, while myrmekite is rarely seen; an indistinct order of crystallisation; greater local
modal variations, with a banding rather than a clustering of the component minerals.

The early quartz-diorite  In its essential minerals, brown biotite, hornblende, slightly zoned plagioclase (composition Ab$_{73-80}$), and quartz, the above rock does not differ from the quartz-diorites found in the main granite. However many features are unusual. These include the very high modal values of quartz, and the presence of micropegmatite and myrmekite, found in association with an appreciable amount of hornblende; the omission of orthite from the accessories. Orthite is ubiquitous in the rocks of the main granite; and the development of phenocrysts (?) of plagioclase, enclosing biotite and quartz.

The early quartz-diorite is considered to be a felspathised semi-basic rock.

The Karaya microgranite  The Karaya microgranite is a fine-grained rock with an allotriomorphic granular texture. Apart from occasional microphenocrysts of microcline (<1.5 mm. in diameter), the grain size of the rock is $<2<5$ mm. Modal analyses indicate a considerable variation in the ratio plagioclase : microcline (Table 7).

The chemical analysis of JR. 966 is given in Table 1, analysis No. 25. Optical properties given below are determined from this rock.

Microcline occurs in the normal texture of the rock, and also as small phenocrysts enclosing biotite and quartz grains. The typical microcline twinning is always present, but (cf. the main granite)
perthitic intergrowths are seldom seen and are restricted to rare fine rods of plagioclase oriented parallel to (010).

The plagioclase is turbid, full of sericite and muscovite. Some of the grains show albite twinning, others are not twinned. Refractive indices, on (010) tablets, give values of \( N_\alpha \) (minimum) = 1.530, \( N_\gamma \) (maximum) = 1.540, indicating a composition of Ab\(_{94-94}\).

The biotite is similar to that of the main granite, altering to green chlorite and having a pleochroism of I pale yellow, Y and Z dark brown. Muscovite is found not only as a secondary product associated with plagioclase, but also as primary flakes (\(< .4 \text{ mm long})\). Optical properties of this muscovite were \( 2V = 42^\circ \), refractive indices \( N_\alpha = 1.560, N_\gamma = 1.598 \).

Magnetite, and occasional minute (\(< .1 \text{ mm})\) crystals of apatite, were the only accessories noted.

**Xenolithic material**

It proved something of a rarity to examine an outcrop of the granite in which accidentally included material was not present. Such material included large rafts of metasediments, smaller rafts, often broken up or veined by granite, and xenoliths. The xenoliths are almost ubiquitous, the larger rafts being restricted in occurrence. Xenoliths are shown in Plate V, fig. 2, and in figs. 18 and 19.
The roof pendant at Babban Tunga is over three miles long. There is a further small pendant to the south of it. Exposures are very poor in these pendants, restricted almost entirely to the marginal contact hornfelses. Large rafts were noted near the contact south-east of Kagara, between mileposts 24 and 21 along the western contact, and adjacent to the metasedimentary strip preserved near the middle of the granite east of Tegina. A typical example is that seen on the whaleback immediately east of the road at milepost 23. This was a maximum of five feet wide, and at least sixty foot long.

In this accidentally included material semi-pelitic and micaceous xenoliths are common, quartzitic types equally so only south of Tegina. Amphibolitic rocks were rare, and occurrences were noted of meta-arkose, talc-tremolite rock and calc-silicate granulite. With the exception of the unusual talc-tremolite rock, these rock types are represented in the envelope of the granite.

Fig. 18. Fragmented xenolithic raft, seen in section. Quarry 2 1/4 mile south of Kagara. Traced from photograph.
The semi-pelite and micaceous types contain the assemblage biotite-quartz-muscovite-(albite-microcline). Garnet may occur. These rocks are frequently felspathic, containing porphyroblastic oligoclase, less commonly microcline. An example of the growth of felspar in a xenolith is usually sharp, and often marked by a biotite-rich rim. These xenoliths are normally fine-grained, and often have a hornfelsic texture.

The quartzitic xenoliths contain quartz, muscovite, with some biotite. They are similar to the quartzites formed south of the granite.

In a stream course 1 1/2 miles south of the northern margin of the granite on the path from Tungan Bako to Kagara a raft thirty feet thick was made up of weathered meta-arkose intercalated with amphibolite schist. Amphibolitic rocks were not common in xenoliths. An example seen near the margin of the granite east of Tegina, a dense fine-grained xenolith, was composed of hornblende (with chlorite) 30, biotite 18, sphene 7, quartz 24, plagioclase 19 and accessories 2 (volume per cent).

In the quarry at mile 30.8 xenoliths of talc-tremolite, rimmed by biotite, were recorded. The talc forms a fine-grained aggregate, the tremolite thin prismatic crystals (> 3 mm. long), with refractive indices of $n_l = 1.610$, $n_g = 1.641$. 
At two localities calc-silicate granulite was found in xenoliths. One of these is seen in Fig. 19. Here the granulite forms a band in semi-pelitic material. The mineral association quartz-grossular garnet-clinozoisite-diopside-hornblende-plagioclase, is the same as that already noted from rocks lying outside the granite.
CONCLUSIONS

Rocks of the greenschist facies occur in a zone south of the granite and to the east of it south of Alum. The proximity of these low-grade metamorphic rocks to the Tegina granite indicates that their regional metamorphism is not directly related to the emplacement of the granite.

But the virtual absence of marginal contact metamorphic phenomena, indicating a minimum heat flow from the granite to the country rock, combined with the absence of a chilled margin to the granite, does suggest that the rocks were still 'hot' from the regional metamorphism at the time of the intrusion of the granite. It is therefore instructive to estimate the temperature and depth at which regional metamorphism took place.

Fyfe, Turner and Verhoogen (1958, p.218) consider it unlikely that greenschist facies rocks form below a temperature of 300°C. The upper temperature limit for the almandine-amphibolite facies rocks probably lies close to 600°C. The actual temperature of formation of a particular suite will depend on the pressure variables in relation to the temperature. In the area under consideration the presence of both greenschist and almandine-amphibolite facies rocks suggests an intermediate temperature of formation, possibly in the range 400 - 500°C. (1)

(1) It may also suggest that factors other than temperature and pressure influence the resulting mineral assemblage in metamorphism. Yoder, pointing out that eclogite, amphibolite and green schist facies may co-exist, has recently (1955, p.505) stressed the importance of the variable water content in metamorphism.
Little is known of temperature gradients in the earth's crust. Those measured near the surface have a wide range, but a figure of 47°/mile, corresponding to the average continental heat flow in sedimentary rocks, is commonly accepted.

With a normal gradient greenschist rocks might form at a depth of six miles. Buddington (1959, p. 677) estimates that the rocks of his catazone, the upper limit of which corresponds to the upper limit of the almandine-amphibolite facies, may form below seven miles. Such estimates suggest that the regional metamorphism took place at a depth of six to eight miles below the surface.

The parallel attitude of three separate forms of primary structure, namely xenolith orientation, foliation, and banding, provides evidence that the Tegina granite flowed, essentially vertically, to its present position. Elongation of the mass as a whole, and of the xenoliths, and the banding in it, indicates that the granite was emplaced under a strong lateral pressure.

The general concordance of the granite to the fold axes and foliation of the surrounding rocks relates in time the folding of these rocks to the emplacement of the granite. That is, the granite is synkinematic.

That the main lateral pressure under which the granite was emplaced, was subsequently maintained is clear from:

(1) The concordance of the later Karaya microgranite.
(2) The formation of diagonal shear joints and cross-joints, both of which result in a lengthening of the rock mass, and represent a response to lateral pressure.

(3) The development of secondary structures in and near the south of the granite. These structures, a secondary foliation, and axial extension by tectonic disruption in the south-west and movement in the south-east, parallel the primary structures.

Outcrops of an early quartz-diorite represent a felspathised semi-basic rock. This may or may not have been intruded to its present position.

The main granite forms one unit. The predominant granitic rocks in it are typified by late-forming phenocrysts of microcline. Granodiorite and quartz-diorite are the result of local or marginal contamination. In the zone of banded foliation bands of granodiorite lie in porphyritic granite. The relationship between the two is not intrusive, and in the field it is clear that the granodiorite represents remnant bands in which the phenocrysts of microcline have not developed.

It seems probable that the Tegina 'granite' was intruded essentially as a granodiorite, and that subsequently, with the introduction of potash and silica and the formation of late phenocrysts of microcline, it was altered in bulk composition to granite.

Bowen and Tuttle (1950, p.494) showed that in the system

\[
\text{KAlSi}_3\text{O}_8 - \text{KAlSi}_2\text{O}_8 - \text{H}_2\text{O},
\]

cooling produced two felspars, i.e.
exsolution, below a temperature of 660°C for pressures of up to $\text{H}_2\text{O} = 2000$ kg/cm$^2$. The microcline of the Tegina granite is perthitic, and thus there is a minimum temperature for its formation.

Goranson (1932, p.232 - 3) obtained completely liquid granite under a water vapour pressure of 1000 bars at a temperature of 700 ± 50°C, and obtained partially molten material at lower temperatures. More recently Bowen and Tuttle (1953, p.50) have stated that such melting was a metastable phenomena, and that the true beginning of melting of granite begins at a temperature near to Goranson's values for completely liquid granite.

Contact metamorphism is restricted to the development locally of hornfels near part of a roof zone, and more widespread hornfels pneumatolysis. That there is any contact metamorphism at all indicates a difference in thermal energy level between the granite and the regionally metamorphosed rocks. Such a "disharmonious" relationship (Walton, 1955, p.9) provides further evidence of the intrusive nature of the granite.

The nearness to the roof, and the fact that contact metamorphic effects are slight, suggest that the granite arrived almost "dead" and that its water content was low. These factors, taken in conjunction with the lateral pressure under which the intrusion took place, are all evidence of a low temperature of emplacement.
INTRODUCTION

During the Mineral Survey of Northern Nigeria, 1904 – 1911, Falconer (1911) recognised that there were at least two suites of granitic rocks in the Precambrian. The Younger Granites occur in the main on and around the Jos Plateau, and are restricted to the eastern half of the country. They include some of the finest ring-complexes known, and their identity as a suite is clear (Mackay et al., 1944, Jacobson et al., 1958).

All other granitic rocks have been ascribed to the Older Granites, a complicated suite composed of granitic rocks and related pegmatites, of the members of the granite family, and, less commonly, of intermediate and basic rocks. The essential unity of this suite has not been clearly established. Problems such as the correlation, age, classification and mode of emplacement of these rocks have not been answered satisfactorily. A further problem, closely connected to the stratigraphy of the Precambrian, is whether these rocks were emplaced during only one, or several, plutonic episodes. Part II of this thesis is an attempt to provide explanations for some of these problems.

During the period 1955 – 1959 the writer, engaged on systematic work in the Precambrian, mapped the south-western half of the area 6 – 7° E, 10 – 11°N, an area of some 2500 square miles. This area, half of which is covered by Plate III, includes numerous
members of the Older Granite suite. These have been studied. The
writer has been able to supplement his observations on the Older
Granites by visits to other parts of Nigeria, notably in Kebbi and
Ilorin Provinces (November 1954); over extensive areas in the Western
Region (February 1957); on the Jos Plateau (April 1957); and in Sokoto
Province (April 1959).

Significant contributions to the study of the Older Granites
are few, but include the works of King and de Swardt (1949) on the
Osi area of Ilorin Province; and of Jacobson and Webb (1946) on the
pegmatites of central Nigeria; de Swardt on the Ilesha area; Cope
(1958, unpublished report) on a part of degree sheet 31 in Northern
Nigeria; and Carter (Tait et al., in preparation) on a part of
north-east Nigeria. Use has been made of information from the above,
and also from all other available relevant material (Geological
Survey of Nigeria bulletins, annual reports, unpublished reports,
files, etc.); especially in the section on petrology, and in the
compilation of Plate I. In the text reference to the source of any
such information used is quoted, all other statements and conclusions
being the responsibility of the writer.

Members of the Older Granite suite are widespread throughout
the Precambrian. Their known occurrence is shown on Plate I, on
which some two hundred and twenty masses are recorded. It must be
noted that there has been little systematic mapping within the
Precambrian and plainly there are many more masses as yet unrecorded.
BORNHARDT TOPOGRAPHY

Dominating the landscape developed on the Precambrian in Nigeria are the so-called inselbergs. Their occurrence, and the processes involved in their formation and subsequent destruction, are described in outline below.

In Nigeria the inselbergs are made up of granites and grano-diorites, less commonly of migmatites, i.e. exclusively of acid plutonic rocks, belonging to the Older Granite suite. The term inselberg, or more correctly bornhardt, for these forms are of gneiso-granitic composition (King, 1943, p.83) is a family one, and includes true bornhardts, whalebacks and granite tors. A bornhardt is characterised by curved exfoliation plates and a domed structure, a whaleback is similar but is elongated in one direction, while joint blocks are typical of a tor.

Tors are rare in Nigeria, examples, however, being seen south of Zaria and in the needle-like forms north-east Bichi, near the Cameroons border. The majority of the relief forms are bornhardts and whalebacks, the two commonly being associated. These forms may occur individually, but more often they are grouped. The best among them are striking features. Thus the bornhardts and whalebacks at Idanre in the Western Region rise to a maximum height of two thousand feet above the forest. Dutse Zuma, near Abuja, rises sheer for a thousand feet (Plate VIII, fig. 1). More frequently these features rise for up to five hundred feet above the plain surface. Prominent bornhardts tend to form on the porphyritic or coarse porphyritic granites.
The shape of the bornhardts is not determined by petrological boundaries. It is the writer's experience that in an area of suitable composition prominent relief features never account for more than half of that area, and usually for appreciably less.

Bornhardts are relics that have developed during one or more cycles of erosion. As such an erosion cycle cuts back into an original plain surface, relief forms tend to be blocked out by the incidence of primary jointing. The maximum height of such forms is determined by the available relief, i.e., the amount of lowering of the plain surface. The relief form that develops will be related to jointing and exfoliation, and the relationship of these two. A system of closely spaced rectangular joints would probably result in the formation of a granite tor, while a dominance of longitudinal joints gives rise to whalebacks. In whalebacks and bornhardts the curved exfoliation surfaces are superimposed onto the established joint pattern. The exfoliation plates are themselves commonly cut by joints, and may be surmounted by joint blocks, so that the resulting form is almost invariably composite.

The exfoliation surfaces are considered by many (see for example King, 1942, p.16) to have formed by 'relief of load'. The suggestion is that, consequent on the erosion and unloading of material from above a massive granitic body, curved plates tend to spring away from the main mass of the rock. In Nigeria these plates vary in thickness from a few inches to six feet, and commonly thin out laterally. Profiles of the bornhardts and whalebacks vary enormously
in their declivity but are invariably convex or plane-convex (see for example Plate II). These profiles are not a function of the landscape cycle but represent the actual exfoliation surface.

Provided that a further cycle of erosion is not set in motion, bornhardts and whalebacks will eventually be worn down to low domes and will ultimately be completely disintegrated, as the successive shells of granite break off they are usually quite fresh, and only subsequently are they weathered. On the steeper slopes fragments of the separated carapace tend to break off and slide down to the sharp junction with the plain below, where they disintegrate. Over the whole shell fragments tend to flake off. On flat portions of certain of the low domes the unexfoliated surface may be hummocky, the rock friable, but this is unusual. Weathering also takes place along available joint cracks.

Bornhardt formation is inhibited in only two areas of the Precambrian; the Oban hills in the Eastern Region, and the Jos Plateau.

In the Oban hills Raeburn (1927, p.78) related the non-development of inselbergs to the heavy forest growth and thick soil there. However, heavy forest growth per se does not affect the formation of such features, for one of the finest examples of bornhardt topography in Nigeria is at Ibanre, where the relief forms rise out of thick forest. The controlling factor would appear not to be the general conditions in the humid tropics (cf. Mabbutt, 1952, p.95), but, more specifically, rainfall. At Oban it exceeds
one hundred and twenty inches per year, whereas elsewhere over the Precambrian it rarely exceeds sixty inches per annum.

On the Jos Plateau the Younger Granites, although better jointed, are considerably more resistant to erosion than the Older Granites, and give rise to the major relief features. But it should be noted that the Older Granites buttress parts of the plateau, for example at Miango (fig. 20) and are responsible for the plateau being an entity rather than a series of hills.

Fig. 20. Spatial relationship of Older and Younger Granites from the Jos area. Modified after Black (1958).
Although Precambrian rocks account for about fifty per cent of Nigeria, poor exposures and lack of economic incentive have resulted in little detailed work being carried out in it.

At the end of 1954 the writer commenced systematic mapping in the Precambrian. He was joined by Dr. R.M. Cope and during the period 1955 - 1959 the area 6 - 7°E, 10 - 11°N, was mapped. In this area exposures are better than normal, and the reconnaissance work of Falconer (1911) and Russ (1957) had shown there is considerable variation in rock type and metamorphic grade. The writer mapped the south-western half of Sheet 31(1), part of which is shown as Plate III, the Tegina Sheet.

Two major problems to be solved are the stratigraphy of the metasedimentary rocks, and the relationship of the Older Granites to these metasediments. There is general agreement that the Older Granites, associated with migmatites and metamorphism, are orogenic, but failing a knowledge of the nature of the succession and the relation of the Older Granites to it, their stratigraphical position

(1) Comprising the Tegina Sheet, half of the Kusheiki Sheet to the North and the Alawa Sheet to the East.
<table>
<thead>
<tr>
<th>Phase Group</th>
<th>Eastern</th>
<th>Western</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meta-Schist Group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eastern Meta-schist series</td>
<td>Semi-polished schists, with a varying percentage of phyllite, and some schists.</td>
<td>The Eastern Meta-schist series</td>
</tr>
<tr>
<td>Phylite, quartzite, phyllite, chlorite schists, garnet and sericite schists.</td>
<td>Type area: Tangav Bagram.</td>
<td></td>
</tr>
<tr>
<td>Illite, chlorite, and chlorite schists; green schists; quartzite, feldspar, and chlorite schists.</td>
<td>Type area: Tangav Bagram.</td>
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</tr>
<tr>
<td><strong>Rated Group</strong></td>
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<td></td>
</tr>
<tr>
<td>The Eastern Rated schist series</td>
<td>Archeo schists, frequently chloritic, with intercalated amphibolites.</td>
<td>Quartzite. Type area: Bakhtiari.</td>
</tr>
<tr>
<td>Archeo schists, garnet.</td>
<td>Quartzite. Type area: Tangav Bagram.</td>
<td>Quartzite, Type area: Bakhtiari.</td>
</tr>
<tr>
<td><strong>Matrite group</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. The succession on the south-western half of 1:250,000 Sheet 11.

cannot be determined. Until this study no succession had been established in the Brochkar. That for the south-western half of Sheet 11 is given in Table 6.
Petrology and field occurrence

The area mapped as Plate II, the Tegina batholith and its surroundings, forms a part of the Tegina Sheet. Tegina - Kagar is the type area for the heterogeneous series, and the rocks from this area have already been described in Plate I: the migmatites and meta-arkosic rocks of Plate II are also typical of the wider area of the Tegina Sheet. Descriptions of the remaining rocks of the succession, i.e. the quartzites of the Meta-arkosic series, the Semi-pelite schist series, and the Pebby schist series, follow.

Quartzites Two mineralogical types of quartzite, of distinct occurrence, are recognised.

Those of the north-west are of restricted occurrence on the Tegina Sheet, but can be traced north onto the Kunheriki Sheet. These quartzites are fine to medium-grained, white, gray or buff-coloured rocks. Some variations are flaggy, with muscovite developed along probable original bedding planes; others are granular. Characteristic is sillimanite, which may occur in small lenses associated with muscovite and garnet, may be speckled in the rock, but more commonly is seen only under the microscope in fine felted aggregates.

West of Masukan on the Alami Sheet quartzites containing kyanite occur in an area of some ten square miles (1). Both the kyanite and

---

(1) Similar kyanite-bearing quartzose rocks are recorded elsewhere, and provide the majority of economic kyanite deposits in the world (Temperley, 1953, p.68).
the rock are white when fresh, but are frequently stained red or brown by the hematite present. The quartzites are fine-grained and normally do not carry more than twenty per cent of kyanite, although there are segregations of almost pure kyanite. Muscovite is usually present in these rocks. The kyanite forms medium- or coarse-grained aggregates of sub-radiating crystals, frequently twinned on (100) (see microphotograph, Plate XIV, fig. 1) and has refractive indices of $N_\alpha = 1.724$, $N_\gamma = 1.728$.

The Kongu Semi-pelitic schist series. A belt of phyllites, with associated mica schists and more silty rocks still characterised by a phyllitic texture, extends north-north-east from Sigama. The phyllites form prominent ridges. They are grey, blue or green when fresh, and carry numerous quartz veins. The phyllites may be studded with octahedra of magnetite.

In thin section the phyllites are lepidoblastic chlorite-muscovite-quartz schists, carrying albite, iron ore and tourmaline as accessories.

To the east of the phyllites lie the Pebbly schist series. East of these are schists considered to be the stratigraphical equivalents of the phyllites. These include quartz-biotite-muscovite, quartz-biotite-muscovite-garnet and quartz-muscovite-garnet-staurolite schists. The staurolite occurs in brownish-black crystals up to three-quarters of an inch long, with the larger crystals often showing interpenetrant twinning. In this section the staurolite is brownish and pleochroic, with refractive indices of $N_\alpha = 1.745$, $N_\gamma = 1.757$. 
The Durum Pebbly schist series

The Pebbly schists lie in a synclinal structure within the phyllites. This series probably plunges to the north. Essentially it is composed of quartz-biotite schists, with some gneissic rocks. At one locality, two and a half miles north of Rubu, the rock is conglomerate. The remaining rocks need not, but frequently do, contain scattered pebbles, and some cobbles. These are of quartz, quartzite, arkose, schist, trachyte and granodiorite. These pebbles are almost invariably elongated in the plane of the schistosity of the rocks.

The succession

The succession is outlined in Table 3. There is no unconformity between the various series. Localities where the relationships of these series can be seen are given below, in brackets. Thicknesses given are tentative, for the exposures are poor, the rocks normally highly folded, and measurements could only be made on the limbs of folds.

The quartzites (north of Komunagia) and meta-arkosic rocks (west of the River Kaduna at Zungeru) are interbedded with the gneissic and migmatitic rocks of the Banded group. Most of the meta-arkosic rocks lie near the top of the Banded group, for which a tentative minimum thickness of seven thousand feet has been estimated.

Rocks of the Heterogeneous schist series are superior to the Banded group (west of Tungan-Bako); the Rongu Semi-pelitic schist series lie above the Meta-arkosic series (east of Ryon). The Heterogeneous series is considered to stratigraphically equivalent to the Semi-pelitic schist series. The Durum Pebbly schist series lie above
the main, garnet and staurolite schists, the equivalent of the Semi-
politite schist series (at Sixingl). Estimated minimum thickness of
the Semi-politite schist and Polly schist series are three thousand
and two thousand five hundred feet respectively.

<table>
<thead>
<tr>
<th></th>
<th>GREEN SCHIST</th>
<th>ALUMINITE-AMPHIBOLITE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chlorite zone</td>
<td>Motite zone</td>
</tr>
<tr>
<td>Semi-</td>
<td>Quartz</td>
<td>Muscovite</td>
</tr>
</tbody>
</table>
politite | Muscovite    | Muscovite   |              |                |
|        | Chlorite      |              |              |                |
|        | Motite        |              | Garnet      | Staurolite     |
|        |               |              |              | Staurolite     |
|        |              |              |              | Gismondite     |
|        |              |              |              | Staurolite     |
| Quartz- | Quartz        | Muscovite   |              |                |
| fulgurite | Muscovite    | Muscovite   |              |                |
|         | Muscovite    |              |              |                |
|         |              |              |              |                |
| Quartzite | Quartz       | Muscovite   |              | Sillimanite (?) |
|         | Muscovite    | Muscovite   |              | Kyanite (?)     |
|         |              |              |              |                |
| Basic | Chlorite      | Actinolite  | Biotite      | Flagphyllosite  |
|       |               |              | Muscovite   |                |
|       |               |              | Sphene      |                |
|       |               |              |              | Migardite      |
| Magnesian | Chlorite    | Actinolite  | Biotite      |                |
|        | Magnesite    | Magnesite   |              |                |

Table 9. Some metamorphic minerals from the south-western
half of 1:250,000 Sheet Y1.
Regional metamorphism

The succession has been regionally metamorphosed to form rocks of the almandine-amphibolite and green schist facies. Green schist rocks are areally unimportant and do not account for more than ten per cent of the Tegina Sheet\(^1\). Their occurrence is restricted to parts of each of the series in the Schist group.

In Table 9 typical metamorphic minerals of the area are shown in relation to the grade of metamorphism that they represent. The metamorphism of quartz-fels-pathic, basic and magnesian rocks has already been described in Part I, and here we note only some metamorphic minerals in the semi-pelitic and quartzitic rocks.

Four of the index minerals of pelitic rocks, chlorite, biotite, garnet, and staurolite, were recorded associated with muscovite, quartz, and small amounts of albite, in semi-pelitic rocks of the Schist group. All of them occur in the parallel of Giringi, where a zoning, with increase in grade eastwards, is apparent in the semi-pelitic schist and Pebbly schist series (fig. 22). Elsewhere the relationship between these minerals may be less clear.

The higher index minerals of pelitic rocks, namely sillimanite and kyanite, have not been found in the semi-pelitic rocks. They do, however, occur in the quartzites. Two types of quartzite are known, characterised by sillimanite and kyanite respectively, but in this context these minerals are not indices of a grade of metamorphism.

\(^1\) In the Nigerian Precambrian as a whole they account for considerably less than ten per cent.
Fig. 21. Section across part of the Alawa Sheet.

Fig. 22. Section illustrating metamorphic mineral zoning at Giringi (see Plate III).
Conclusions

A succession, at least 13,000 feet thick, has been established. It includes minor basic and ultra-basic intrusives. A lower, Banded group is composed largely of quartzo-felspathic, quartzitic and migmatitic rocks. Semi-pelitic rocks bulk largely in an upper, Schist group and probably represent a geosynclinal facies.

The rocks of the succession have been regionally meta-morphosed, most of them now belonging to the almandine-amphibolite facies, lesser amounts to the green schist facies.
THE PRECAMBRIAN IN NIGERIA

Most of the Precambrian lying east of the longitude of Kaduna is composed of granitic or migmatitic rocks, in which there only remnants of earlier beds.

As an example, in a part of north-east Nigeria Carter (Tait et al., in preparation) notes that the oldest rocks have been transformed to Older Granite migmatites, metasediments being found only as xenoliths and small pendants in granitic rocks. The rock types found in these include quartzo-felsparic gneisses, biotite and hornblende gneisses, quartzite, marble and calc-silicate rock.

Similar metasediments may occur in larger masses, but the assemblage remains typical of the eastern half of Nigeria, as it is also in the west near the Dahomey border south of latitude 9°30'N.

This rather monotonous pattern of catazonal rocks is more diversified in a broad west-central belt trending roughly north-south, running through parts of the Western Region, Ilorin and Kabba provinces, reappearing in Niger and Zaria provinces, and being traced north into Sokoto province (fig. 23).

Within this belt:–

(1) Metasediments are more extensively developed.
Fig. 23. Zone in which low-grade metasediments are found; and structural trends in the Nigerian Precambrian.
(ii) Green schist facies rocks, notably semi-pelites and pelites, may occur. i.e. mesozonal rocks are found with catazonal in this belt (Buddington, 1959, p.676).

(iii) Structural continuity and trends are better developed.

This is apparent from the early work of Falconer (1911); work in the period 1927 - 1938 by Russ (1957) in Niger and Zaria Provinces, by Tattam (1930) in Sokoto, (1936) in Borgu, Ilorin Province; by various officers of the Geological Survey in Kabba Province and the Western Region in the period 1944 - 1949; by Jones (1952) in Ilorin Province; the work of the writer and of Cope (1958) in Niger and Zaria Province.

Degree Sheet 31 lies in this belt. In the successions established by Cope (1958) and the writer it was shown that, irrespective of metamorphic grade, no unconformity exists between the various series recorded.

The distinctive pebbly schists on Degree Sheet 31 have been found within the last year in Sokoto, and from near Yelwa on the River Niger, and east-north-east of Osi (Allum, personal communication).

Phyllitic rocks are also known from Kabba and Sokoto(1).

---

(1) On the most recent Geological map of Nigeria (1,200,000,1954) quartzite and schist are grouped as a unit apart from the undifferentiated gneiss, migmatite, granite, etc. of the Precambrian. The quartzites and schists which have been mapped all lie in the west-central belt. This grouping of quartzite and schist seems unfortunate, for whereas quartzites may occur anywhere in the Precambrian of Nigeria, low grade semi-pelitic or pelitic metasediments are restricted to this belt. Nor is the writer aware of any exposure where low-grade schists, apart from quartz-schists, are intimately associated with quartzitic rocks.
<table>
<thead>
<tr>
<th>ERA PERIOD</th>
<th>WEST</th>
<th>7°30'E</th>
<th>EAST</th>
<th>TECTONICS</th>
<th>ECONOMIC MINERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPER PRECAMBRIAN</td>
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<tr>
<td>BASEMENT COMPLEX</td>
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<tr>
<td>LOWER AND/OR MIDDLE PRECAMBRIAN (Archean &amp; Birimian Systems)</td>
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<tr>
<td>PRECAMBRIAN</td>
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<td>OLDER GRANITE</td>
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<tr>
<td>Schist Group</td>
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<tr>
<td>Pebby schist series</td>
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<tr>
<td>Phyllite series</td>
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<td>Banded Group</td>
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<td>Metachroase series</td>
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<td>Migmntite series</td>
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<tr>
<td>OLDER GRANITE</td>
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<tr>
<td>Late-kinematic Synkinematic including pegmatite, porphyrhic facies migmatite</td>
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<tr>
<td>OLDER GRANITE</td>
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<td>SYNTHETIC</td>
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<td>OLDER GRANITE</td>
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<tr>
<td>(Synkinematic) including pegmatite, porphyrhic facies migmatite</td>
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<tr>
<td>YOUNGER GRANITE</td>
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<td>Granitic phase</td>
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<tr>
<td>Volcanic phase</td>
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<tr>
<td>GVARIAN COMPLEX</td>
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<tr>
<td>Gneissos and migmatites, with subordinate Schist, amphibolite quartzite marble</td>
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<tr>
<td>BASEMENT COMPLEX</td>
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<td>(≡ Gwarian Complex)</td>
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<tr>
<td>TECTONICS</td>
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<tr>
<td>Tear-faulting</td>
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<td>Isoclinal folding</td>
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<td>ECONOMIC MINERS</td>
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<tr>
<td>Columbite</td>
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<tr>
<td>Wolfrum</td>
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<tr>
<td>Pyrchnite</td>
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Fig. 24.
PETROLOGY

The dominant rock type in the Older Granite suite is a porphyritic or coarse-porphyritic biotite granite. Numerous other rock types occur. Many of the porphyritic granites are closely related to migmatites. Granodiorite and quartz-diorite may occur as margins to the porphyritic granites, but are not common as separate masses. The suite also includes other granite types; occasional occurrences of basic or intermediate rocks; and abundant late acid products, notably pegmatite and aplite.

The occurrence of many of these rock types, and examples from them are detailed in the following section.

A. Basic Rocks

Gabbroic rocks and a norite have been recorded from the Cameroons; pyroxenite and gabbro from north-east Nigeria; meta-gabbros from Osi, and norites from the Osi area, Ilorin Province.

Carter (Tait et al., in preparation) has recorded numerous small masses of non-foliated fine- to medium-grained melanocratic rocks from north-east Nigeria. Basic and intermediate rock-types found include acid and basic diorites, gabbro and pyroxenite.

These rocks are poorly exposed as irregular masses pendant in the granites. Their original form is uncertain but their widespread
occurrence as xenoliths suggests that they originally covered considerable areas. There is evidence that these rocks were plastic and mobile at the time of the ensuing Older Granite granitisation, and they are regarded as an early basic phase of this cycle.

Bosse of norite are known east, south-west and north-west of Osi, in Ilorin Province. The writer has examined such a boss immediately south of Osu Aran, some nine miles to the north-west of Osi. The rock is fine-to medium-grained and dark in colour.

In thin section it (cf. 12) has an allotriomorphic-equigranular texture, and is composed of hypersthene 54%, augite 12%, biotite 12%, plagioclase 20 (per cent) with accessory quartz, iron ore and zircon.

The hypersthene is frequently appreciably altered to biotite. It is not pleochroic. With a 2V of ± 62° and N = 1.710 a composition of En33 is indicated (Poldervaart, 1950, p.1076); the plagioclase is fresh, twinned on the albite law and is calcic andesine; the biotite is strongly pleochroic, with X pale brown < Y = Z reddish brown.

Examples noted by King and de Swardt (1949, p.19) to the east and south-west of Osi differ from the above in being coarser-textured, in containing pleochroic hypersthene, and not containing clinopyroxene.

King and de Swardt (1949) have recorded sheeted masses of metagabbro within or along the contacts of the porphyritic granite at Osi. The central parts of these sheets are formed of a medium-grained
rock composed of plagioclase, hornblende and biotite, with subordinate quartz. Towards the margin the rock assumes a gneissose foliation and ultimately it becomes a schistose rock in which biotite predominates over hornblende. King and de Swart have shown that the metagabbros pre-date the porphyritic granite, and they consider that their metamorphism does so too. They suggest that the metagabbros may originally have been noritic in composition. The norite occurrences noted above are all within twelve miles of 0ai. They are not metamorphosed and a close time-relationship between their emplacement and that of the porphyritic granite seems likely.

There is little evidence on the origin of these basic rocks, but presumably they are related to an original basaltic magma.

The Orthopyroxene-Bearing Rocks

Orthopyroxene occurs in the norites of the 0ai area, is known in certain of the basic rocks of north-east Nigerin, and is also found in the pyroxene diorite at Makichi. (see p.85)

Orthopyroxenes are characteristic of the charnockite suite of rocks. Falconer (1911, p.138) recorded a hypersthene-bearing quartz-diorite porphyrite from Toro, north-west of Jos which he considered to show "a certain affinity with the basic members of the charnockite series."

True charnockitic rocks are associated with high-grade granulitic
rocks; typically they have also a greasy look in hand specimen. The
writer has not been able to trace Falconer's specimen, but specimens
from the other localities do not have this typical appearance. Nor are
they associated with granulitic rocks, but rather with the Older Granite
suite. They are not considered to be charnockites.

B. Intermediate Rocks

Syenites

Syenites from the Older Granite suite are known from the Solli
hills north of the Jos Plateau, the Kaltungo inlier in north-east
Nigeria, from Iliwa and from Ejk, in Niger Province, and from the Banche
area.

At Banchi Baan (1926) noted that within several of the bigger
masses of 'porphyritic older granite' (sio) of the area two rock types
can be recognised:

(i) Biotite granite, carrying more hornblende than the normal
porphyritic granite.

(ii) Pyroxene syenite, with distinctive large brown phenocrysts of
feejar. A few earlier syenite dykes were also recorded. The pyroxene
syenite is composed of orthoclase(1), albite, quartz, myrmekite,

(1) The writer was anxious to examine the orthoclase of this rock. A
specimen recently collected for him from the locality cited was
found to be a porphyritic diorite. Bain mentions dioritie rocks
further east.
hornblende, enstatite and (?) diopside.

Bain states that there is no regular mode of distribution for the above two types. In some outcrops the syenitic types are in the centre, in others they are marginal, while in many cases the two types appear to be intimately intermingled. Contacts between them are gradational. This gradation suggests that the syenite at Bauchi has formed by the contamination of granitic material.

At Kuki a small semi-circular body of quartz-syenite, probably of dyke-like form (see Plate III) has been mapped (Truswell, 1938). The quartz-syenite is intrusive into porphyritic granite, against which it may show a weak marginal foliation.

The rock is equigranular, fine to medium-grained, dark cream to pinkish in colour, and has a low colour index. The ferromagnesian mineral present is hornblende, which tends to form in clusters that may partially or completely enclose other minerals of the rock. Locally, with increase in quartz and the appearance of small amounts of biotite, the rock grades towards granite.

The mode of JF. 834 (analysed specimen) is given below:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Volume per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcline microperthite</td>
<td>55.0</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>19.4</td>
</tr>
<tr>
<td>Quartz</td>
<td>19.0</td>
</tr>
<tr>
<td>Hornblende</td>
<td>4.2</td>
</tr>
<tr>
<td>Micropogonite</td>
<td>1.8</td>
</tr>
<tr>
<td>Accessories (sphene, magnetite, biotite, zircon, rutile)</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The crystals of microcline microperthite are up to 4mm. in length.
The majority of them contain up to 30 per cent of clear albite, exsolved in irregular-shaped blebs. Less commonly the perthitic intergrowth is of replacement type. In this, inclusions and areas of enclosed or partially enclosed twinned oligoclase, in optical continuity, are set in microcline, which may itself have subsequently exsolved small amounts of albite: plagioclase. In two crystals an anti-perthitic relationship, with oligoclase replacing microcline, was observed. The plagioclase varies in composition from An_{18-19}. It is turbid and saussuritized, with the development of small amounts of epidote. Hornblende may have optical continuity over areas of several millimetres, but within such areas it is fragmented and contains inclusions of other minerals, notably microcline. It is pleochroic with X (yellow green) < Y (green) < Z (blue-green), may alter to chlorite, and has refractive indices of \( N_\alpha = 1.638, N_\gamma = 1.660 \). The quartz grains do not exceed 1 mm in diameter.

**Diorite**

Few dioritic rocks have been described from the Older Granite suite. A description of that at Makichi is given below.

The Makichi diorite is a poorly exposed stock-like mass outcropping sporadically over some five square miles in the south-east of the Kucheriki Sheet (see Plate I).

Small exposures of fine-grained norite were seen near the
centre of the mass. The remainder of it is composed of grey, fine- to medium-grained porphyritic pyroxene-diorite grading to quartz-diorite.

Modal analyses of typical rocks are given in Table 10.

<table>
<thead>
<tr>
<th></th>
<th>JF 805 Norite</th>
<th>JF 807 Pyroxene diorite</th>
<th>JF 949 Quartz</th>
<th>(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>.40</td>
<td>.57</td>
<td>.51</td>
<td></td>
</tr>
<tr>
<td>Hypersthene</td>
<td>.26</td>
<td>.4</td>
<td>.1</td>
<td></td>
</tr>
<tr>
<td>Diopside</td>
<td>.13</td>
<td>.10</td>
<td>.11</td>
<td></td>
</tr>
<tr>
<td>Biotite</td>
<td>.10</td>
<td>.17</td>
<td>.14</td>
<td></td>
</tr>
<tr>
<td>Hornblende</td>
<td>.8</td>
<td>.1</td>
<td>.2</td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td>.</td>
<td>.8</td>
<td>.14</td>
<td></td>
</tr>
<tr>
<td>Myrmekite</td>
<td>.</td>
<td>.1</td>
<td>.3</td>
<td></td>
</tr>
<tr>
<td>Ilmenite</td>
<td>.2</td>
<td>.</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>Accessories</td>
<td>.1</td>
<td>.2</td>
<td>.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 10. Modal analyses of rocks from the Makishi stock (volume per cent).

The norite is composed of plagioclase (Ab₇₅), foxy-red biotite, non-plagioclase hypersthene, augite, green hornblende, small amounts of ilmenite, and accessory quartz, sericite, calcite and apatite.

Characteristic of the diorites and quartz-diorites are large plates of plagioclase up to 1.5 cm. long. This plagioclase is slightly zoned, varying in composition from Ab₆₈-₇₆. Quartz varies up to 15 per cent in the mode, and small amounts of myrmekite are present in the more acid rocks. The same ferromagnesians are present as in the norite.

(1) Analysed specimen. Table 1, analysis No. 4.
with brown biotite dominant. Augite is more abundant than hypersthene, and hornblende normally occurs only as thin rims to the pyroxene.

Dioritic rocks are commonly considered as hybrids (see for example Shand, 1949, p.277). There is little direct evidence but it is suggested that the above diorite may have formed by the reaction of basic magma with acid country rock.

Granodiorite, quartz-diorite

Granodiorites and quartz-diorites occur as marginal facies to porphyritic granites, less commonly in separate masses. The Tegina granite includes a good example of the former mode of occurrence, and as an example of the latter the granodiorite at Kedaka is described below.

Kedaka lies in the extreme south-east corner of the Tegina Sheet. The granodiorite measures four miles north-south by a maximum of two and a half miles east-west. The rock is a strikingly uniform medium-grained slightly porphyritic biotite granodiorite.

The mode of JP.650 is quartz 32, plagioclase 43, microcline 7, biotite 11, micropegmatite 4, accessory epidote, sphaene, zircon 2 (volume per cent). The mode and chemical analysis (Table 1, analysis No. 18) of specimen JP.650 indicates that this rock is a quartz-rich granodiorite.

In thin section, the texture of the rock is characterised by
irregular outlines and mutual interference of the grains. Plagioclase
laths are ~3½ mm. long. Quartz grains, biotite fragments and microcline
crystals have their longest axes ~1½ mm. long.

The plagioclase is zoned, of composition An_{24-11}. Apart from a
clear rim the plagioclases are partially sanauiritised, with the
development of secondary zoisite, sericite, muscovite and a little
calcite.

Hornblende does not occur in the rock. Associated with the
biotite is accessory zircon, sphene and pleochroic epidote. Epidote
is unusual as a primary constituent in rocks of the Older Granite suite,
in which orthite is the normal member of the epidote family present.
In the slide of JP.650 one crystal of orthite was seen, rimmed by
epidote.

**Acid rocks**

Porphyritic and coarse porphyritic granites. These rocks are the most
widespread and common rock type of the Older Granite suite. They are
caracterised by coarse phenocrysts of microcline up to 5 cm. long,
by a medium- to coarse-grained groundmass, and by biotite as the
dominant ferromagnesian. The porphyritic rocks may exhibit sharp
contacts against earlier rocks, but more frequently they grade to, or
intermingle with, migmatitic types.

Two examples of porphyritic granite are given: the Tegina granite
has already been described, and a description of the granite at Osi follows. It should be stressed that the development of late phenocrysts of microcline micropertidite noted in the Regina granite is not unique to that granite, but rather is characteristic of these porphyritic rocks.

The porphyritic granite at Osi. King and de Swarut (1949) have described the porphyritic granite from Osi. It occurs in an oval-shaped mass, with its longer axis NNE - SSE, in an area of approximately 50 square miles. The southern margin of the mass has a relatively smooth curved form, in contrast to the northern margin, which is deeply embayed by gneiss and metagabbro. Around these embayments the contact is often indefinite, and granite is itself extensively developed within them. The junction between the porphyritic granite and the gneisses is quite sharp along the greater part of the contact, but in a number of localities more complex marginal relations are encountered. Transitions between banded gneiss and porphyritic granite along zones of varying width have been recorded. In these zones diffuse bands of gneiss and relic gneissose structures are common.

The main porphyritic granite is preceded by an early granitisation phase, and within it are occasional small bodies of late leucocratic granite. But the porphyritic granite constitutes the major part of the granite mass.

The granite is composed of euhedral phenocrysts of microcline,
between 2 and 5 cm., in length, in a groundmass composed of quartz and biotite, together sometimes with subordinate hornblende.

Crystals of late-forming microcline commonly include rounded blebs of quartz, oligoclase and biotite. Smaller plates of microcline also occur. Oligoclase occurs both in association with quartz in patches, and as larger, more rectangular plates. The latter are characterised by twin lamellae, and usually contain rounded blebs of quartz, or even of earlier oligoclase.

NYRMELITIC INTERGROWTHS BETWEEN QUARTZ AND OLIGOCLASSE ARE COMMON. NYRMELITE RARELY AFFECTS THE LARGER OLIGOCLASSE PLATES, BUT IS EXTENSIVELY DEVELOPED IN SMALL PLATES OF CLOUDY OLIGOCLASSE ADJACENT TO MICROCLINE. THESE PLATES ARE USUALLY CONSIDERABLY ROUNDED AND ALBITISED. QUARTZ FORMS IRREGULAR CRYSTALS OR AGGREGATES SMOOTHLY ENHANCING THE OLIGOCLASSE AND CONTAINS ROUNDED INCLUSIONS OF MICROCLINE, OLIGOCLASSE AND BIOTITE. THIS QUARTZ IS PROBABLY LATE-FORMING LIKE THE MICROCLINE PHENOCRYSTS. THE QUARTZ NOTED (ABOVE) AS INCLUSIONS IN MICROCLINE, ETC., IS CONSIDERED TO REPRESENT RELICS OF EARLIER-FORMED NODULES. BIOTITE CRYSTALS TEND TO OCCUR IN CLUSTERS, OR ELSE AS FLAKES CONFINED TO THE INTERSTICES BETWEEN THE PRINCIPAL MINERALS. HORNBLINDE HAS A SIMILAR MODE OF FORMATION. ACCESSORY MINERALS PRESENT ARE SPHEINE, IRON ORE, ORTHITE, APELITE AND ZIRCON.

**Equigranular fine- or medium-grained granites**

On the Tegina Sheet the writer has mapped ten biotite-unsomite or biotite granites. Although these rocks may be marginally foliated
they have sharp contacts with the surrounding rocks. The Karaya
microgranite\(^{(1)}\) intrusive into the Tegina granite, is a typical example
of this type. Its mineralogy has already been described in some detail.

While remaining concordant to the general structure these rocks
post-date the porphyritic Older Granites. In Kamba Province similar
rocks, for example that at Isanlu Makatu (see fig. 30) (Jacobson, verbal
communication) are also later than the porphyritic granite. But in the
north-east of Nigeria Carter (Tait et al., in preparation) records rocks
of similar mineralogy, the most widespread type in the area, as
representing a granitisation phase transitional between the felspath-
isation of the migmatites and the formation of coarse porphyritic granite.

At Kusheka in Niger Province Cope (1958) has recorded an almost
circular intrusion, accompanied by a number of dykes to the south-east,
of augirine-augite microgranite. This rock contains quartz 39,
microcline 34, albite 22 and augirine-augite 5 (volume per cent).
The association of microcline with a soda pyroxene is unusual.

**Early fine-grained granites**

In the eastern half of the country, for example, on the Jos
Plateau, at Bauchi (Bain, 1926, p.56), and in north-east Nigeria

\(^{(1)}\) The term microgranite is here used for fine-textured granitic
dykes. Masses of similar texture but other form are referred
to as fine-grained granite.
(Carter, in preparation), fine-grained light-coloured granites and adamellites, containing biotite or biotite and muscovite, occur. These are the fine-grained felspathic Older Granites of Dain, the fine-grained discordant intrusions of Carter.

The fine-grained granites form veins and dykes up to thirty feet thick, and irregular masses extending for up to two hundred yards.

These rocks show sharp discordant contacts with earlier basement rocks, and clearly pre-date the porphyritic Older Granites and migmatites.

Late acid rocks

Aplites and pegmatites, with related quartz-tourmaline and quartz-mica veins, are widespread in, and exterior to, members of the Older Granite suite\(^{(1)}\). They are most abundant in roof zones of migmatitic rocks, where an intricate pattern of ramifying pegmatite, and aplite, veins is typical (see fig. 11).

**Pegmatites** Many occurrences are known in which these pegmatites carry tin and columbite-tantalite. This is especially the case in a broad belt extending across central Nigeria from west and south of the Jos Plateau to Egbe in Kabba Province (see Plate I). The pegmatites

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\(^{(1)}\) A further group of pegmatites is to be found in metasomatized rocks of the Precambrian. These pegmatites, as is frequently recognised in metamorphic areas (Samberg, 1952, p.248) are, however, a phase of granitisation.
from this area have been described by Jacobson and Webb (1946)

They vary from a few feet to over a mile in length, from a few inches to thirty feet in width. The majority are in regular tabular bodies with fairly constant dip and strike, although many of them display a pronounced pinch and swell structure. The dykes are often in sub-parallel groups.

The pegmatites fall into three main groups: microcline-perthite-quartz pegmatites, microcline-perthite-quartz-mica pegmatites, and quartz-mica veins. Certain quartz-tourmaline and quartz-andalusite-sillimanite veins are intimately related to the pegmatites.

Jacobson and Webb consider that the primary crystallisation of microcline-perthite, quartz, and a little acid plagioclase during a magmatic or epi-magmatic stage of pegmatite formation has, under suitable conditions, been succeeded by the transformation of that pegmatite to more complex types by solutions richer in soda, silica, hyperfusibles and rarer elements. Albitionisation, and mineralisation, are characteristic of these later types. A hydrothermal stage is represented primarily by associated quartz and quartz-tourmaline veins.

Most abundant are the microcline-microperthite-quartz-mica pegmatites. The complex varieties of this type give rise to the bulk of the economic deposits, in which muscovite is normally the predominant mica.

Many of the calcitised pegmatites display a rude banding parallel to the walls of the intrusion, caused by the alternation of
bands of coarse pegmatite and lenses of fine-grained albite.

**Other late acid rocks** On the Tegina Sheet four miles south-east of Mariga are outcrops, up to one hundred and eighty yards across, of leucocratic granite. Clear quartz grains and pink or yellow felspars lie in a medium-grained, structureless rock.

The mode of this rock is microcline 39, quartz 37, albite 19, with small amounts of myrmekite, muscovite and secondary chlorite. Plates of microcline have diameters of up to 4 mm. Plagioclase and myrmekite are interstitial to the quartz and microcline. Some of the microcline is in micrographic intergrowths with quartz.

The form of this leucocratic granite is not known. It is not considered to be dyke-like. Hooker has recently (1958) recorded massive pegmatitic granites up to four hundred yards across north of Ibadan, in the Western Region, that may well be of similar form.

Aplo-granites are known from the Osi area of Ilorin Province (King and de Swart, 1949) and from north of Ilesha (de Swart, 1953, p.26) (Table I, analysis No. 27). The aplo-granite from the latter occurrence is composed of a fine-grained aggregate of quartz and felspar with subordinate amounts of biotite. Small scattered phenocrysts of microcline may be present. The aplo-granites are found as patches up to fifteen feet wide in both granite-gneiss and porphyritic granite. The aplogranite may grade into porphyritic granite.
D. Contact Metamorphism

Intrusive Older Granites are in a minority. Contact metamorphic effects related to them are rarely seen. On the south-western half of Degree Sheet 31 the writer has recorded three small occurrences of calc-silicate hornfels, and at a further four localities sillimanite-mica hornfels was noted adjacent to Older Granite.

Two types of calc-silicate hornfels were seen. In the mission compound at Ureggi (see Plate III) a light greenish-grey spotted diopside-grossularite-wollastonite hornfels was recorded.

<table>
<thead>
<tr>
<th>JF. 464</th>
<th>Volume %</th>
<th>The mode of this rock is recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite</td>
<td>27</td>
<td>opposite.</td>
</tr>
<tr>
<td>wollastonite</td>
<td>24</td>
<td>On the left bank of the R. Mariga</td>
</tr>
<tr>
<td>Diopside</td>
<td>7</td>
<td>+ eight miles north of where it enters</td>
</tr>
<tr>
<td>Garnet</td>
<td>20</td>
<td>the Tegina Sheet a small outcrop of</td>
</tr>
<tr>
<td>Quartz</td>
<td>8</td>
<td>idocrase-diopside skarn was noted.</td>
</tr>
<tr>
<td>potash felspar</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>oligoclase</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Accessory iron ore, sphene</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

The idocrase forms coarse (>4 cms.) brown vitreous striated prismatic crystals, with refractive indices of $N_\alpha = 1.705$, $N_\gamma = 1.726$.

The sillimanite hornfels have a characteristic assemblage of biotite-muscovite-quartz-garnet-sillimanite. An account of those developed near the Tegina granite has already been given. West of Kusheiki (see Plate I) these hornfelses are developed sporadically over an area of five square miles in a roof zone dotted with
occasional outcrops of granodiorite.

The slight contact metamorphic effects suggest that these rocks had a low water content at the time of intrusion.
CHEMISTRY

Twenty-seven analyses are available of rocks from the Older Granite suite. They include five of basic and intermediate rocks, six granite and granodiorite gneisses, twelve porphyritic granites, two microgranites and two aplogranites. The preponderance of analyses of granitic rocks is a reflection of their predominance in the suite.

Six of the analyses (Nos. 4, 5, 10, 18, 24 and 25) are new. The remainder are from King and de Swardt (1949), four analyses; de Swardt (1953), five analyses; and Russ (1957), twelve analyses. Russ' analyses include nine of porphyritic granites. The writer has mapped the localities of seven of these.

Chemical analyses are given in Table 1. Tables 2, 3, and 11 are of the norms, Niggli values, and cations in the standard cell, of the analysed rocks. Variation diagrams of the suite are shown as figs. 25 - 29 inclusive.

Specific gravities of the rocks range from 2.60 to 2.99. The aplogranites average 2.615, the microgranites 2.65, and the porphyritic granites 2.65. The pyroxene diorite from Makichi (No. 4) has a specific gravity of 2.80; the norite from near Osi (No. 1) of 2.99.

The number of cations in a standard cell of one hundred and sixty oxygen ions (Barth, 1948, p.53) have been calculated for the analysed specimens, and are shown in Table 11. The calculated values
are between 90.1 and 101.7. The intermediate rocks have values from 96 to 98.

All the rocks of the 'granite family' in the suite fall within the range of 91.9 to 95.2 (see also fig. 29). Exception to this is analysis No. 23, with a cation count of 90.1. Marmo (1955, p. 413) has recorded a variation in the number of cations of a standard cell from certain West African (post-Birimian) granites of between 90.6 and 98.2.

<table>
<thead>
<tr>
<th>Analysis No.</th>
<th>Cations in standard cell</th>
<th>Analysis No.</th>
<th>Cations in standard cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>101.7</td>
<td>15</td>
<td>94.4</td>
</tr>
<tr>
<td>2</td>
<td>96.9</td>
<td>16</td>
<td>94.4</td>
</tr>
<tr>
<td>3</td>
<td>97.3</td>
<td>17</td>
<td>93.6</td>
</tr>
<tr>
<td>4</td>
<td>97.6</td>
<td>18</td>
<td>95.2</td>
</tr>
<tr>
<td>5</td>
<td>96.0</td>
<td>19</td>
<td>92.7</td>
</tr>
<tr>
<td>6</td>
<td>94.9</td>
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<td>12</td>
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<td>13</td>
<td>94.1</td>
<td>27</td>
<td>92.7</td>
</tr>
<tr>
<td>14</td>
<td>95.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 11. Number of cations in the standard cell of rocks from the Older Granite suite.
Fig. 25. Niggli values of the analysed rocks of the Older Granite suite.
Niggli values, of Al, Pm, C, and Alk, plotted against Si as ordinates, are given in figure 25. Si varies from 117 to 433. Pm diminishes, i.e. with increasing Si values, from 54 to 6 along a curve that is concave upwards. In contrast, Al increases from 19 to 45 along a curve that is convex upwards. C and Alk values lie on or near straight lines, C decreasing from 21 to 2, Alk increasing sharply from 6 to 43. The values of K (the ratio molecular $K_2O : Na_2O$) increase with Si from .12 to .60. The porphyritic granites have K between .36 and .60, the majority, however, having values between .46 and .54. Mg decreases with Si from .66 to .12.

Weight percentage of silica has been plotted against weight percentage of lime, and of alkalis. The lime and alkalis bear a normal

Fig. 26. Potash plotted against soda (weight per cent) for the analysed rocks if the Older Granite suite
antipathetic relationship to one another (fig. 26). Peacock (1931, p. 65) suggested that the point where the alkali and lime trends cross, expressed in terms of the silica percentage, provides an index for a given suite of rocks. The scant information available from the Older Granite suite indicates an alkali - lime index of 57 to 59, and suggests that the suite can be classified as calc-alkaline.

In fig. 27 molecular proportions of alumina have been plotted as ordinate against total molecular lime, soda and potash. Values of the

![Graph](image-url)

**Fig. 27.** Lime, and alkalis, plotted against silica (weight per cent), for the analysed rocks of the Older Granite suite.

former vary from .127 to .178, of the latter from .102 to .196. The porphyritic granites, with the microgranites and aplogranites, have alumina values between .127 and .154, while total lime and alkalis,
with the exception of analysis 23, 102, have values between .125 and .150. The ratio in all these rocks lies close to one, which corresponds to the join between peraluminous and metaluminous fields of Shand (1949, p.228). The majority of these granites have alumina slightly in excess of lime and alkalis, i.e. they fall in the peraluminous field.

Weight percentage of soda has been plotted against weight percentage of potash in fig. 28. The porphyritic granites have potash:

![Graph](image)

**Fig. 28.** Potash (weight per cent) plotted against soda.

soda ratios of 1.9 to 0.9. A comparatively narrow range in soda, of 2.95 to 4.29, is to be compared with the wider range, 3.46 to 6.54, of potash in these porphyritic granites.
The porphyritic granites vary only little in their molecular proportion of total alkalis, for although the overall variation of the suite is between .45 and .135, the granites form a compact group with values between .97 and .119 (fig. 29).

![Graph showing the relationship between alkalis and aluminium oxides for the analysed rocks of the Older Granite suite.](image)

**Fig. 29.** Total line and alkalis plotted against alumina (molecular per cent) for the analysed rocks of the Older Granite suite.

Small amounts of the following oxides have been determined in certain of the analyses\(^1\): \(\text{TlO}_2\) (27), \(\text{MoO}\) (20), \(\text{BaO}\) (16), \(\text{SrO}\) (9), \(\text{La}_2\text{O}\) (9), \(\text{Cl}\) (13), \(\text{F}\) (10), \(\text{S}\) (26), \(\text{Fe}_2\text{O}_3\) (27), \(\text{ZrO}_2\) (15), rare earths (4), \(\text{Cr}_2\text{O}_3\) (9), and \(\text{V}_2\text{O}_5\) (9). Some of these are found in the characteristic accessory minerals of the suite: \(\text{Fe}_2\text{O}_3\) (.03 - .38%), \(\text{Cl}\) (nil - .03) and \(\text{F}\) (nil - .10) in apatite; \(\text{TlO}_2\) (.06 - .095) in sphene and ilmenite.\(^2\)

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\(^{1}\) Figures in parenthesis indicate the number of these analyses.
$\text{ZrO}_2$ (nil - 0.09) in anorthite; and rare earths (nil - 0.04) in orthite.
$\text{TiO}_2$ and $\text{P}_2\text{O}_5$ are present in greater amounts in the more basic rocks. $\text{BaO}$ (trace - 0.04) and $\text{SrO}$ (trace - 0.03) are probably camouflaged in the felspar, $\text{Li}_2\text{O}$ (0.02 - 0.06) in mica. In most cases $\text{CO}_2$ (nil - 0.42%) is present as secondary calcite, while $\text{S}$ (trace - 0.12%) occurs as small amounts of pyrite. $\text{Cr}_2\text{O}_3$ (0.01) and $\text{V}_2\text{O}_5$ have been noted in the norite, analysis No. 1.
STRUCTURE

The rocks of the Older Granite suite may be massive, but are more commonly foliated. Where massive, these rocks may develop local or marginal foliation. If present, foliation is formed of biotite foliae. Less commonly felspar phenocrysts are aligned. Truly gneissic rocks are rare. Structures within the migmatites are often complicated. Jointing and exfoliation are ubiquitous. Mylonites and shear zones are commonly developed. Normally these latter are relatively small-scale phenomena, but extensive mylonite zones are known, as for example at the Kurra Falls at the south-east of the Jos Plateau, and to the south-east of Maiduguri in the Northern Cameroons.

Little detail is available concerning the structure of individual masses. In the literature structural observations on the Older Granites are usually restricted to a note on the absence or presence of a foliation. Exceptions are the Regina granite (see Table 4) and the granite at Osi. The latter (King and de Swart, 1949, p.22) is an oval-shaped mass, some 50 square miles in extent, with its longer axis NEW. - SSE. The northern contact is deeply embayed and irregular while the southern margin has a relatively smooth curved form. Flow layering, represented by a parallelism of biotite flakes and many of the felspar phenocrysts, is present throughout the mass, being more pronounced towards the contacts. The flow-layering shows small-scale undulations, but in general parallels the contacts, which favour two
definite directions, trending NW. or ENE. King and de Swardt consider that the inward-dipping foliation at the south, and the vertical or steep inward dip of the foliation in the east and west indicate that the mass is not batholithic. They suggest that it is a pitching funnel-shaped mass. The foliation of the surrounding gneisses has been deflected towards parallelism with the contact in the south, but to the north such deflection is slight.

Tabula (1932, p. 473) introduced a classification of granitic rocks based on their position in an orogenic evolution. Those formed at an early stage of orogeny he called syngnomatic, those formed at a later stage being late-kinematic.

Criteria have been evolved for the distinction of these two types in the field. Those given in Table 12 have been used by the writer for the Nigerian Older Granites.

<table>
<thead>
<tr>
<th>Syngnomatic granites</th>
<th>Late-kinematic granites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predominantly concordant</td>
<td>Discordant</td>
</tr>
<tr>
<td>Contacts commonly gradational; less frequently sharp</td>
<td>Sharp contacts</td>
</tr>
<tr>
<td>Foliation, xenoliths, etc., frequent</td>
<td>Foliation, xenoliths, rare</td>
</tr>
<tr>
<td>Usually relatively coarse, often porphyritic. Commonly related to migmatites and mylonites</td>
<td>Fine-grained</td>
</tr>
<tr>
<td>Field evidence may indicate metasomatic, less commonly intrusive emplacement</td>
<td>Field evidence suggests intrusive emplacement</td>
</tr>
</tbody>
</table>

Table 12. Field criteria for the distinction of syngnomatic and late-kinematic granites.
This table represents a considerable modification and simplification of a similar table given by Morse (1955, p. 431). In the Older Granites of Nigeria synkinematic granites need not have gradational contacts; a metasomatic origin is not necessarily implicit in their definition, nor are the anlaysed synkinematic "granites" normally granodioritic or quartz-dioritic in composition (cf. Morse, op. cit., p. 431 - 2).

The Older granites are in general concordant. Such a relationship is difficult to establish in the eastern and far western parts of the Precambrian, where the granitic rocks are more often associated with migmatites, but can be more readily seen in the central belt (fig. 23).

Fig. 30. Older Granites and structural trends in the Precambrian of Kebbi Province. After Geol. Survey Nigeria (? 1945)
In this belt structural trends and fold axes may be deflected around the larger granitic masses (see for example fig. 30, and Plate III) but actual discordance is only local. The smaller masses tend to be entirely concordant, and may even be phacolithic in shape.

Apart from minor late acid rock types, such as aplogranite, aplitite and pegmatite, the writer is only aware of two small masses of Older Granite that are definitely late-kinematic. These are the quartz-augite at Kuki, and the aegirine-augite microgranite from Kuchaka, Niger Province. The fine- and medium-grained biotite-muscovite granites from the Tegina Sheet have sharp contacts, little or no foliation, and are intrusive, but they are concordant. Later than the porphyritic granites they may well be late-synkinematic.

Nearly all the Older Granites are synkinematic. The significance of this is considered to be great. On Degree Sheet 31 Cope (1958) and the writer recognised a definite cycle: sedimentation was succeeded by orogenic conditions, involving regional metamorphism folding and the emplacement of the Older Granite suite(1). I.e. in this area all the Older Granites were emplaced in one complex orogeny. The similarities of structure and rock type in the central belt, and the failure to demonstrate a regional unconformity anywhere in the Precambrian suggests that all the Older Granites can be related to the same orogeny.

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(1) For this cycle, which was concluded by faulting, the term Gvarian complex was proposed.
THE BASEMENT COMPLEX

The source of the sediments of the Guarian Complex is not known, although clearly they have been derived from an earlier basement.

Of interest are the granite pebbles and cobbles found in the Giringi Pebbly schist series. Although deformed these are associated with quartz, quartzite, schist and arkose pebbles and cannot represent later veins, subsequently disrupted. Earlier than the sediments that contain them, these granite fragments thus pre-date the Older Granites. Possibly they represent a similar orogenic culmination to an earlier sedimentary cycle. Pettijohn (1943, p. 936) discussing the significance of granitic pebbles from Archaean Conglomerates of the Canadian Shield, considered that the earlier granites, from which the pebbles were derived, are probably wide-spread but unrecognised at the present erosion level. The writer doubts if this is the case in Nigeria.

Recently (April, 1959) the writer was shown a quartz-felspar-epidote granitic gneiss at Anka in Sokoto Province. Bordering this to the west were interbedded pebbly schists and purple metamorphosed shales. Some of the pebbles were identical in mineralogy and texture to the adjacent unusual granitic rock. A low-dipping foliation in the granitic rocks is to be contrasted with the vertical schistosity of the metasediments. This apparently simple relationship between sediments and an earlier basement is, however, complicated at the eastern margin of the granite where there is an intrusive contact with similar, although non-pebbilferous, metasediments to those further west.
The granite-gneiss is intrusive into the rocks of which it is the basement. It probably represents the earlier basement, partially re-mobilized during the (later) Older Granite orogeny. Eskola (1946, p.164) has described similar features from the Karelian belt of east Finland.
CORRELATION AND AGE

The West African Precambrian has been sub-divided into four systems: these are the Falemian, the Tarkwaian, the Birrimian, and the Archaean (see for example Bodin, 1952, p.17). All are folded, but the Falemian is not metamorphosed. The Tarkwaian rests unconformably on the earlier rocks.

Neither the Tarkwaian nor the Falemian are developed in Nigeria, and the stratified rocks of the Nigerian Precambrian must be referred to the Archaean and/or the Birrimian systems of the Lower and Middle Precambrian (1) (fig. 31). The Older Granites are thus post-Archaean or post-Birrimian in age. If it can be assumed that the orogenic conditions under which the Older Granites were emplaced followed closely after sedimentation (ie. that the concept of the Gwarian Complex is valid) then these granites can be pre-Birrimian, or post-Tarkwaian and post-Birrimian.

Throughout West Africa (French West Africa, Bodin (op. cit., 1952); Sierra Leone, Pollet (1951), Marmo (1955); Ghana, Junner (1954), Murray (1957); French Camerons, Gasel et al. (1956), similar granites have been shown or are considered to be post-Birrimian in age (see Table 13). Granites of this type can be traced from Ghana through Dahomey into Nigeria. Junner (op. cit., 1954) and others have indeed likened the Nigerian Older Granites to the Post-Birrimian ones of Ghana and elsewhere.

(1) Junner (1954, p.120) has, however, expressed doubt at the validity of the Birrimian system, suggesting that it may represent less metamorphosed Archaean.
This correlation is accepted.

The absolute age of the Older Granites is uncertain. They pre-date the Younger Granites (as can be seen on the Jos Plateau at Miang, and on the west side of Kof, (fig. 20)) for which an age of \( \pm 550 \) million years (i.e. late Precambrian) has been established; and they post-date all the other rocks in the Precambrian.

Only one age determination is available for the Older Granites. Lepidolite from a pegmatite dyke associated with Older Granite from Dogon Daji, Kabba Province, was analysed using the Rb/Sr ratio method, and gave an apparent age of \( 625 \pm 60 \) million years (Nicolaysen et al., 1953, p.342). It is uncertain what reliance can be placed on this result. Six further specimens from granite and pegmatite, including one from the Turiga granite, have been submitted for age determination. Two different methods, using the K/A and Rb/Sr ratios will be used on all these specimens. It had been hoped that results from these analyses would have been to hand, but when available they should provide a more exact dating of the Older Granites.

It should be noted, however, that age determinations from other post-Birimian granites in West Africa are not consistent. Galenas derived from pegmatites associated with concordant granites in the Sula mountains of Sierra Leone gave conventional ages of 2890 million years (Holmes and Cahen, 1954, p.29), 2890 and 3020 million years (Eberhardt et al., 1955, p.99); while an upper limit of age for certain granites from French West Africa, three from the Ivory Coast, one each from
Haute Volta and Haute Guinee, deduced from the ages of galenas in auriferous quartz veins, ranged from 2150 - 2200 ± 70 million years (Marvier, 1957).
CLASSIFICATION

The great majority of the rocks of the Older Granite suite are granodiorites and granites, with related migmatites. It is the classification of these rocks with which we are concerned.

Granitic rocks have been classified in several ways. Bases of classification include texture, mineralogy, chemistry, contact relations, and position in an orogenic cycle. Table 13 gives an indication of the variability of the classifications adopted for the post-Birimian granites in other West African territories.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>CLASSIFICATION</th>
<th>SOURCE OF INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRENCH WEST AFRICA</td>
<td>Discordant batholiths (late) 1. calc-alkaline 2. alkaline Concordant calc-alkaline batholiths (early)</td>
<td>Boaïn (1952, 1956)</td>
</tr>
<tr>
<td>SIERRA LEONE</td>
<td>Late-kinematic granites 1. potassic 2. sodic Synkinematic granites</td>
<td>Barro (1955)</td>
</tr>
<tr>
<td>GHANA</td>
<td>Dixoove type Winneba type Cape Coast type</td>
<td>Murray (1957)</td>
</tr>
<tr>
<td>FRENCH CAMEROONS</td>
<td>Late-syntectonic granites Early-syntectonic granites</td>
<td>Gassel, Houré, and Nickles (1956)</td>
</tr>
</tbody>
</table>

Table 13. Classification of the post-Birimian granites in other West African territories.
In the Nigerian Precambrian poor exposures often limit the observations that can be made on the granitic rocks, their contacts and relationships to the surrounding rocks. Nevertheless it is possible to adopt a fourfold classification for them.

(1) Those which grade to anatectic migmatites.
(2) Those which are intrusive in migmatitic areas.
(3) Those which are intrusive into regionally metamorphosed, but not metasomatized, rocks.
(4) Those which are intrusive and unconnected to metamorphism.

The Younger Granites, in which successive granitic rocks and related porphyry stocks, often chilled against one another, are associated with volcanic rocks in ring-complexes, form the representatives of group (4). Kennedy and Anderson (1938) distinguished between volcanic and plutonic associations among rocks. Volcanic associations include all intrusions genetically related to volcanic activity and originating in the same magmatic source, and are found in non-orogenic areas. The Younger Granites are typical of this association. In contrast the rocks of the plutonic association are granitic and granodioritic in composition, are emplaced in close association with orogenic movement, and present abundant evidence of processes of assimilation and contamination in their formation. The Older Granites, of contact types (1) (2) and (3) fall in this latter association.

Contacts of types (1) and (2) can be found throughout the Precambrian, of type (3) only in the central zone also characterised by low-grade metasediments (see fig. 23).
The relationship of granite type to structural level has been much discussed. Druce (1941, p. 42) subdivided the granites genetically associated with the crystalline schists of the masses central in France into three. Firstly the anastatic batholiths, formed in place, with variable textures and easy margins. Secondly the subaustroclastic batholiths, closely associated with the first type, but occurring along axes of maximum insignificant and definitely cutting the country rocks. And thirdly normal or intrusive batholiths, plainly intrusive and cross-cutting, in which the granite has lost contact with its original surroundings. Druce's classification is adopted here for the older granites, the three types being referred to as (1) anastatic granites, (2) subaustroclastic granites and (3) intrusive granites. These types correspond essentially to the anastomatic parasubclastic and intrusive granites of Read's granite series (see for example Read, 1949 b, p. 149). A textural classification of the older granite is given below in Table 14.

<table>
<thead>
<tr>
<th>POLDERNESS SIZE</th>
<th>&gt; 3 cm.</th>
<th>&lt; 3 cm.</th>
<th>No phenocrysts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>COARSENESS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 5 mm</td>
<td></td>
<td></td>
<td>Coarse even-grained granite</td>
</tr>
<tr>
<td>1-5 mm</td>
<td></td>
<td></td>
<td>Medium-grained granite</td>
</tr>
<tr>
<td>&lt; 1 mm</td>
<td></td>
<td></td>
<td>Microgranite</td>
</tr>
<tr>
<td>GRANUL碱</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very coarsely porphyritic granite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarsely porphyritic granite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarsely porphyritic granite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarsely porphyritic granite</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 14. Textural classification of the Nigerian Older Granites.

The known limits of the suite lie within the heavy line.
The predominant type is a porphyritic granite, which, with
increase in the size of the phenocrysts, grades to a coarsely
porphyritic granite. Phenocrysts longer than 5 cm. are not known.
The normal observed variation in the size of the groundmass is 1 - 4 mm.
The Tagina granite, with a groundmass of quartz and biotite of ± 1 mm.
is an example lying close to the granite porphyry field. Further work
on the Older Granites may well show that granite porphyries occur.

Microgranites, apart from small veins, are much less common.
They grade to medium-grained granites.

The overall textural range is thus relatively narrow. The units
in the table above are taken from Scholitz (1945), who describes a
much greater size variation in the Younger Precambrian granite plutons
of the Cape Province (op. cit., p. xlvii).

Chemical classification

Simonen (1948) showed that there are distinct differences in
the chemical composition of synkinematic and late-kinematic granites
in the Svecofennide orogeny in Finland. Norwo (1955) has applied
similar criteria in differentiating two chemical groups for certain
West African (= post-Nirrmin = Older) granites. The inference
is that these groups correspond to those of the synkinematic and late-
kinematic granites.
In Table 15, twenty-three of the analysed rocks from the suite are listed, classified firstly according to their petrochemistry using Irvine's criteria, and secondly according to their position in the orogeny, based on field observations.

<table>
<thead>
<tr>
<th>Rock type (no. of analyses in brackets)</th>
<th>Petrochemical classification Irvine (1955)</th>
<th>Structural classification, based on field observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz syenite (5)</td>
<td>?</td>
<td>Late-kinematic</td>
</tr>
<tr>
<td>Granite and granite-diorite gneisses (6-11 inclusive)</td>
<td>Synkinematic (6,7) Late-kinematic (8,9,10,11)</td>
<td>All synkinematic</td>
</tr>
<tr>
<td>Pegmatitic Granites, etc. (12-23 inclusive)</td>
<td>All Late-kinematic</td>
<td>Synkinematic (12, 13, 14, 15, 16, 18, 19, 20, 21) Unconstrained (22, 23), probably synkinematic. Late kinematic? (17)</td>
</tr>
<tr>
<td>Microgranites (24,25)</td>
<td>Late-kinematic</td>
<td>Late synkinematic or Late-kinematic</td>
</tr>
<tr>
<td>Plagiogranites (26,27)</td>
<td>Late-kinematic</td>
<td>Late-kinematic</td>
</tr>
</tbody>
</table>

Table 15. Comparative classifications: petrochemical classification of Irvine, and field observations.

From the above it is clear that the Nigerian Older Granites do not fit Irvine's petrochemical classification for the West African granites of which they are part.

Irvine has used four analyses from the among his examples. Of
The two expressions correspond, although post-quantum

possibly
different, do not differ from them in their

density.

equal volume from 90.1 - 95.2 (see Fig. 5, 25 - 29).

120°F : 20°F 0°C = 0.9

0.95 • 20°F X 0°C (Km0 + Km0) = 68.95 - 74.7°F per cent.

the experimental deviation of which induces 50% variation of

In addition, however, the poroplastic grantees do form a

values from 0°F do not fall on the established trends (Fig. 25).

50% of the poroplastic type, but at may be of interest to note that Mr.

gelatin-enzyme and other enzymes can provide no evidence of

when measured. The one measured into-kinnematic member of the suite

papain of the Meila occurrence. The latter, whose number's disintegrated

stemineare and late-kinnematic grantees closer account must be
to grante of oil. If a poroplasticlallation is to be related to

grante on the grante grante to be related to the course poroplastic

Kingu and de Saunt (1949) did not consider the kinnematic bound

poroplastic grantees are significant in their Meila occurrence. Again,

noted, however, that both the kinnematic bound grantees and the course

and on appropriate (25) at the late-kinnematic phase at the late-poroplastic grantees (12).
MODE OF EMPLACEMENT

The subject of the origin and mode of emplacement of granite has been much discussed. It has persisted as a problem primarily because granitic rocks form at depth and their formation cannot be observed. But also because, theoretically, granite can be derived from several sources (1), because of the ambiguity in usage of certain terms (2), and because of the tendency of many observers to over-extrapolate their findings.

At present almost general agreement seems to have been reached that granitic rocks can form in different ways, and that the problem has become one of the relative abundance of the granitised masses and the intrusive masses, and of the source of the intrusive material and the granitising emanations (3).

(1) For example, granite may represent primary magma, may have formed by the fractional crystallisation of basalt, by the paligenesis or refusion of sialic material or by granitisation.

(2) The use of the word intrusive is an instructive example of this ambiguity. To some (eg. Buddington, 1959, p.740; Crowder, 1959, p.376) the use of the term implies a truly magmatic rock. Others (eg. MacGregor and Wilson, 1939, p.210; Read, 1948, p.18) consider that complete fluidity is not essential for an intrusive rock, and that a mush containing not more than a quarter of its volume in a liquid state could equally well account for the observed facts.

(3) Granitisation is defined here as the process whereby rocks are converted to rocks of granitic character without passing through a magmatic stage. To the writer the concept of 'wet' granitisation, utilising fluids, ichors or emanations, as envisaged by Soderholm (1934), Read (1951) and others, seems a more reasonable modus operandi than a 'dry' granitisation resulting from the migration of ions, as suggested by Backlund (1946) and Reynolds (1947).
It has already been noted that the Older Granites include anatectic, subautochthonous and intrusive types and that with few exceptions their formation was synkinematic to an orogeny. It is also considered that all the Older Granites are related to one complex orogeny.

The process of the formation of anatectic granites in place can be observed in the field. An example of it has already been described in the migmatites east of the Tegina granite. There, banded gneisses grade through migmatites with pronounced structures and migmatites with fainter structures to granitic rocks, the rock becoming steadily more homogeneous in appearance.

As examples of subautochthonous and intrusive contact types from the Tegina Sheet: granite is intrusive into migmatitic rocks at Zambugga, eight miles north-west of Mogaga; while the Tegina granite is intrusive, in part, into regionally metamorphosed rocks.

Two problems remain. The source of the granitising material and the relationship of the metasomatic granites to the intrusive granites. The writer feels less competence in dealing with these questions, which cannot be answered in the field. However, it is suggested that the process of metasomatic granitisation involves the squeezing out and upward movement of the constituents of lowest melting point from the zones of the folded belt during the orogeny. It is also considered that the intrusive granites represent mobilised metasomatic granites emplaced at a higher level. They would thus correspond to the intrusive granites of Read's granite series (see Read, 1949, 149 - 151).
<table>
<thead>
<tr>
<th>ROCK TYPE</th>
<th>Metamorphic processes</th>
<th>Pseudomorphisation, freskpathisation</th>
<th>Further pseudomorphisation</th>
<th>Maintenance of</th>
<th>Points of</th>
<th>orogenic conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelitic or semi-pelitic rock</td>
<td>Augen gneiss</td>
<td>Migmatites with faint nebulitic structures</td>
<td>Metasomatic granites</td>
<td>Intrusive granites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternating successions, i.e., including basic or psammitic bands</td>
<td>Banded gneiss</td>
<td>Migmatites with pronounced relict banded and structures</td>
<td>Further homogenisation</td>
<td>Migmatites with faint nebulitic structures</td>
<td>Metasomatic granites</td>
<td>Intrusive granites</td>
</tr>
</tbody>
</table>

Table 15. A diagrammatic representation of the mode of formation of the Older Granites
SUMMARY

Rocks of the Older Granite suite occur throughout the Nigerian Precambrian, bornhards formed on them characteristically dominating the landscape.

The Precambrian of the east and far west of Nigeria is composed largely of granitic and migmatitic rocks of the Older Granite suite. A central zone is more diversified. In it metasediments are more extensively developed and include mesosomal pelites and semi-pelites. A succession established in this zone is shown to be conformable throughout. Indeed, no unconformity has been demonstrated anywhere in the Precambrian on a regional scale.

Dominant in the suite are granitic rocks and related migmatites. Granodiorite and quartz-diorite do not often form separate masses, are more common closely related to granitic rocks. Occurrences of other intermediate and of basic rocks are infrequent, and usually form intrusions pre-dating the granites. Pegmatites from a central belt are the only mineralised rocks in the suite.

The most characteristic of the granitic rocks is a porphyritic or coarse porphyritic biotite granite. The granitic rocks include metasomatic and, less commonly, intrusive types.

The emplacement of the suite is related to orogenic conditions. Criteria indicate that all but two of the known occurrences are
syndinastic. It is thought that all the rocks of the suite were formed in one complex orogeny.

Variation diagrams indicate a distinct field for the porphyritic granites. The one analysed late-kinematic granite is anomalous when plotted with the other analyses.

Granitic pebbles, from metasediments earlier than the Older Granites, show that an earlier basement contained granitic rocks.

The Older Granites are correlated with the Post-Birimian granites of West Africa. They are Precambrian, but their absolute age remains uncertain.
ACKNOWLEDGEMENTS

I am indebted to Dr. R.R.E. Jacobson, Director of the Geological Survey of Nigeria, for permission to carry out this study, and for his assistance to me in many ways.

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I have greatly appreciated the assistance given to me by colleagues in the Geological Survey of Nigeria; in particular by Mr. G. Jefford, who carried out six silicate analyses; Mr. T.P. Johnstone, whom I assisted in the preparation of the microphotographs and photographs of hand specimens; and Dr. R.N. Cope, with whom I had the pleasure of working on the same project during the period 1955 - 1958.

I would like to take this opportunity of thanking my wife very sincerely for her co-operation, help, and sympathy to me at all times during the work on this thesis. Her more tangible assistance included typing the draft and colouring in the maps.
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| Table 1. Chemical analysis of rocks from the Older Granite Suite |
|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
|                         | Basic rocks             | Intermediate rocks      | Granite and granulite    | Pegmatite or coarse pegmatite | Granite and granulite   | Pegmatite or coarse pegmatite | Granite and granulite   | Pegmatite or coarse pegmatite | Granite and granulite | Pegmatite or coarse pegmatite |
|                         | 1           | 2          | 3          | 4          | 5              | 6              | 7              | 8              | 9              | 10         | 11         | 12         | 13         | 14         | 15         | 16         | 17         | 18         | 19         | 20         | 21         | 22         | 23         | 24         | 25         | 26         | 27         |
| Na₂O                    | 57.05       | 57.16      | 57.22      | 60.57      | 62.99         | 64.30         | 64.69         | 69.08         | 70.23         | 70.35        | 70.19      | 63.95      | 62.06      | 69.40      | 69.63      | 69.95      | 70.01      | 70.25      | 70.65      | 71.02      | 72.08      | 72.05      | 71.17      | 70.93      | 71.13      | 72.35      | 73.13      |
| Fe₂O₃                   | 2.26        | 2.24       | 2.12       | 1.62       | 1.50          | 1.45          | 0.97          | 0.65          | 0.47          | 0.95          | 0.65        | 0.97        | 0.57        | 0.65        | 0.72        | 1.23        | 0.62        | 0.65        | 0.56        | 0.40        | 0.19        | 0.58        | 0.18        | 0.56        | 0.17        | 0.08        | 0.03        |
| CaO                     | 0.28        | 0.30       | 0.30       | 0.32       | 0.34          | 0.35          | 0.37          | 0.39          | 0.38          | 0.37          | 0.34        | 0.38        | 0.40        | 0.35        | 0.38        | 0.38        | 0.39        | 0.39        | 0.38        | 0.39        | 0.39        | 0.39        | 0.39        | 0.39        | 0.39        | 0.39        |
| K₂O                     | 0.02        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| Na₂O                    | 0.02        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| CaO                     | 0.04        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| MgO                     | 0.01        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| CaO                     | 0.01        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| MgO                     | 0.01        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| CaO                     | 0.05        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| MgO                     | 0.05        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
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| MgO                     | 0.05        | -          | -          | -          | -             | -             | -             | -             | -             | -             | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           | -           |
| Total                   | 100.49      | 100.98     | 99.91      | 100.13     | 99.08         | 100.25        | 100.39        | 100.34        | 99.35         | 99.57         | 99.77       | 100.23      | 100.35      | 100.34      | 99.39       | 99.91       | 100.46      | 100.39      | 100.56      | 99.94      | 100.35      | 99.97      | 100.65      | 99.94      | 100.65      | 99.77      |
| CaO                     | 2.39        | 2.60       | 2.61       | 2.68       | 2.70          | 2.67          | 2.66          | 2.65          | 2.65          | 2.63          | 2.67        | 2.61        | 2.65        | 2.63        | 2.60        | 2.67        | 2.61        | 2.65        | 2.63        | 2.60        | 2.67        | 2.61        | 2.65        | 2.63        | 2.60        | 2.67        |

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### Table 3. Rhenium values of rocks from the Old Granite Suite

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Plate IV

Fig. 1. Drag-folding in mylonitic quartzite. 1¼ miles SSW. of the south-eastern tip of the Tegina granite.

Fig. 2. Incipient tectonic disruption, showing necking down of microgranite vein. Near granite margin east of Tegina.
Plate V

Fig. 1. Rafts of metasediment in granite. 1 3/4 miles south-east of Tegina.

Fig. 2. Xenolith in granite. Within the xenolith original microstructures are preserved. Light-coloured patches are felspar crystals. 3/4 mile east of Tegina.
Plate VI

Fig. 1. Elongate xenoliths of metasediment in marginal quartz-diorite. Crossed by aplite, with fretted margin. 7/8ths. mile SSE. of Tegina.

Fig. 2. Banded migmatite traversed by semi-concordant pegmatite. Note light-coloured concordant offshoots from the pegmatite, and the dark meta-basite band. 2½ miles east of mile 17.5, Zungeru-Kaduna road.
Fig. 1. Talc-carbonate schist. The schists dip away from the observer, and plunge at a low angle to the left. 2½ miles south of Kagara.

Fig. 2. Part of minor fold in meta-arkoses. River Kaduna, north of railway bridge at Zungeru (see Plate I).
Plate VIII
BORNHARDT TOPOGRAPHY

Fig. 1. Dutsin Zuma, Abuja, Niger Province.
Fig. 2. Dutsin Kwatarkwashi, Sokoto Province.

(See Plate I).
Plate VIII

BORNHARDT TOPOGRAPHY

Fig. 1. Dutsin Zuma, Abuja, Niger Province.

Fig. 2. Dutsin Kwatarkwashi, Sokoto Province.

(See Plate I).
Plate IX

Fig. 1. View of the northern part of the Kusheriki hills, taken from the west (see Plate I).

Fig. 2. Whaleback at Kagara.
Plate X

AERIAL PHOTOGRAPHS IN STEREOSCOPIC PAIRS.

Figs. 1 & 2. Granite (G), talc-carbonate (TC) and chlorite schist (C), and migmatite (M). North and northwest of Kumunu.

Figs. 3 & 4. Granite relief. Dutsin Pandidi, 4 miles SSE. of Kushneriki (see Plate I).
Plate XI

AERIAL PHOTOGRAPHS IN STEREOSCOPIC PAIRS.

Figs. 1 & 2. Mylonitic quartzite (MQ) striking into south-eastern tip of the Tegina granite (TG).

Figs. 3 & 4. Fold closure in quartzites at Konungaia (see Plate III).
Plate XII

HAND-SPECIMENS

Fig. 1. JF. 299. Large tablets of microlite in granodioritic base. 2½ miles east of mile 17.5, Zungeru-Kaduna road.

Fig. 2. JF. 992. Contact of granodiorite and granite. ¼ mile east of Tegina.

Fig. 3. JF. 916. Cataclastic texture in granite. From near south-east tip of Tegina granite.

Fig. 4. JF. 683. Cobble of granodiorite, from the Durumi Pebby Schist series, 1 mile north of Giringi (see Plate III).
Porphyritic granite. JF. 990, from Tegina. Phenocrysts of microcline microperthite are surrounded by a fine groundmass of quartz, micropegmatite, microcline and plagioclase.

Crossed nicols, x 10.

Microgranite. JF. 966, from Karaya. The rock is equigranular and the habit of the microcline is to be contrasted with that of Fig. 1.

Crossed nicols, x 15.

Quartz-diorite. JF. 899. Contaminated margin of Tegina granite west of the road at mile 26. A large hornblende plate (H) encloses garnet (G).

Crossed nicols, x 15.

Pyroxene-diorite. JF. 805, from Makichi on the Alawa Sheet. Hypersthene (H), diopside (D), and biotite (B).

Ordinary light, x 20.
Plate XV
MICROPHOTOGRAPHS.

Fig. 1. Porphyritic granite. JF. 1007, from Tegina.

Crossed nicols, x 7.

Fig. 2. Orthite crystal. JF. 1000, from granite south-east of Tegina. The dark rim is of epidote. The crystal is metamict and cracks near the bottom left of it probably represent auto-radiation.

Ordinary light, x 15.

Fig. 3. Muscovite-chlorite-quartz schist. JF. 327, from schist belt east of the Tegina granite. The rock has been smeared out along a movement zone.

Crossed nicols, x 8.

Fig. 4. Banded calc-silicate granulite. JF. 900, from xenolith in the Tegina granite west of the road at Mile 26. The dark band is rich in garnet, chlorite and hornblende, the remainder in quartz, with some clinozoisite, diopside, and some calcite.

Ordinary light, x 12.