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MINERALISATION ASSOCIATED WITH THE NIGERIAN MESOZOIC RING COMPLEXES

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ABSTRACT.—The anorogenic younger granites of northern Nigeria have evolved along two separate petrographic trends and each has its differing associated mineralization. The peralkaline trend shows a dominantly dispersed phase while the biotite granites have an early dispersed phase, in which columbite may be important, followed by a late-stage vein controlled cassiterite/sulphide rich phase of mineralization. Throughout these phases zinc is a more abundant element than tin while the associated tungsten plays a less important role than earlier writers imply. An abundance of minor ore minerals associated with the cassiterite and columbite phases of mineralization have also been discovered.

PART 1

MINERALIZATION AND ITS REGIONAL SETTING

INTRODUCTION

There are two distinct periods of tin mineralization in Nigeria. An earlier Palaeozoic mineralization possibly related to orogenic calc-alkaline magmatism at the close of the Pan-African thermo-tectonic event and a later Mesozoic mineralization associated with the formation of subvolcanic anorogenic granites as ring complexes. The style of each mineralization as well as the associated minerals is very different and may simply be related to contrasting tectonics and magma evolution. (MARTIN and PIWINSKII 1972).

The Palaeozoic tin mineralization is limited and confined to some quartz-mica-feldspar pegmatites in the Kafanchan region (Fig. 1). These may consist of microcline, oligoclase, biotite, muscovite, lepidolite, apatite and garnet as well as quartz, whilst cassiterite and tantalite are important economically. Varieties of beryl and green and pink tourmalines are also worked on a minor scale for gemstones.

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In contrast the anorogenic Mesozoic granites of Northern Nigeria (Fig. 1), do not contain tourmaline or tantalite but in some localities have high concentrations of columbite. They also contain rare-earths, uranium and thorium-rich accessory minerals and most important of all abundant sphalerite with cassiterite, chalcopyrite, galena, pyrite, topaz and fluorite, whilst monazite, arsenopyrite, genthelvite, pyrrhotite and molybdenite also occur. Zinc is an enriched trace element in the anorogenic granites concentrating in the micas and amphiboles up to 1% wt. ZnO and it is therefore not surprising that the principal ore mineral in many of the mineralized veins is sphalerite which in some instances far exceeds the amount of cassiterite.

GENERAL GEOLOGY

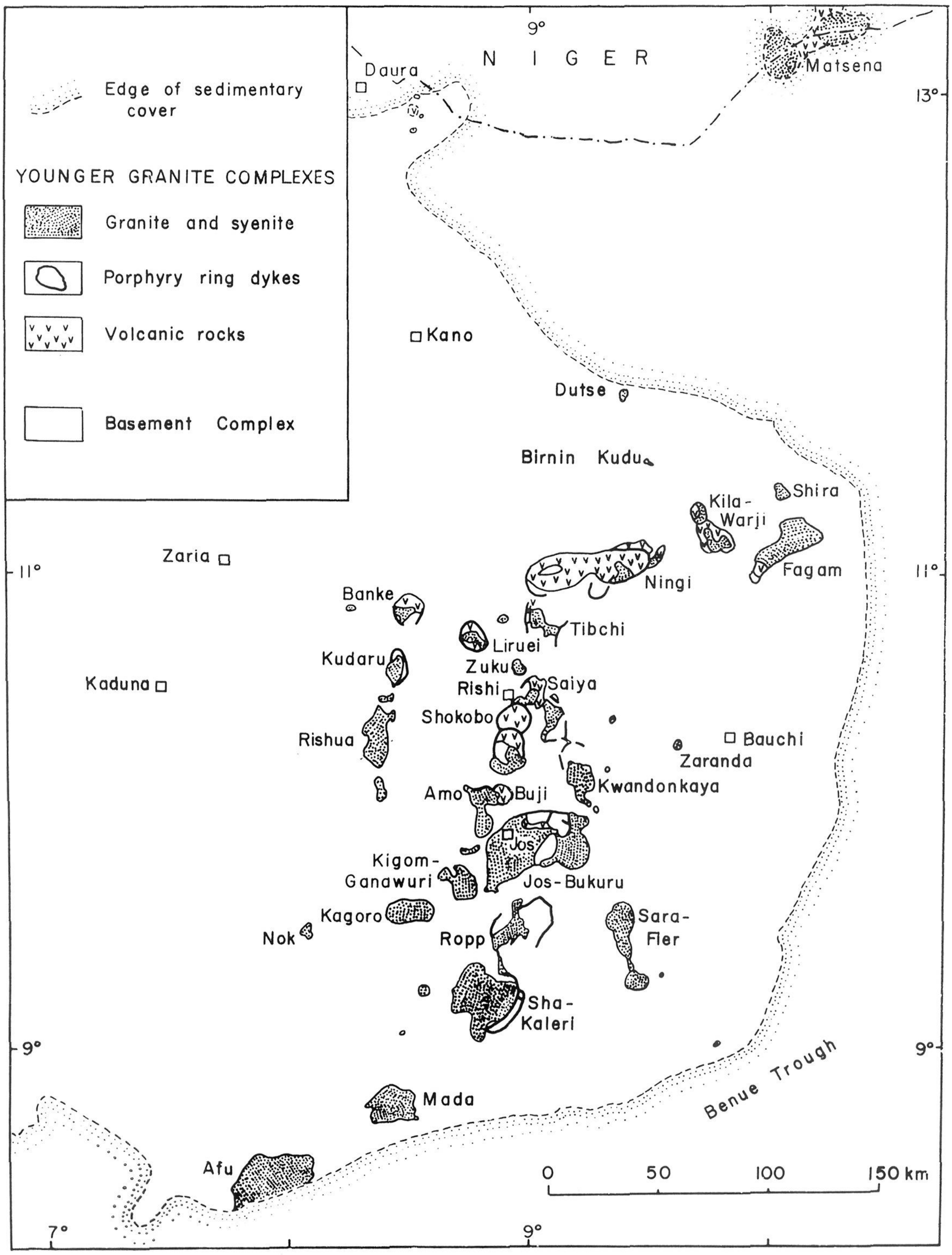
The anorogenic granites of northern Nigeria (the younger granites), were intruded at a high level into the late Precambrian to lower Palaeozoic basement as ring complexes. Over 40 individual complexes occur and range in size from 1.500 Km^2 to less than 2 Km^2.

In general this suite of complexes is concentrated in a 200 Km. wide zone as chains of complexes extending along the ninth meridian. The zone, which extends from the Niger Republic, 1.200 Km. south to the margin of the Benue trough in Nigeria, represents successive periods of continental mid-plate magmatism which migrated southwards.

Typically, the complexes are circular or elliptical in outline, 10-25 Km. in diameter and defined by an outer fayalite-granite-porphyry ring-dyke surrounded by basement.

Although the distribution of the ring complexes is to some extent controlled by the Pan-African structural trends in the 'basement' rocks the subvolcanic centres vary greatly in structural complexity.

Studies in the north of Nigeria (Bowden and Turner in press.) have shown that the development of these complexes began with the eruption of basalts (olivine tholeiites, quartz tholeiites) from central volcanic vents. These were associated with trachy-andesites, trachytes and minor rhyolites. During subsequent caldera collapse voluminous sequences of rhyolitic ignimbrites dominated the volcanic assemblage. Later, post-caldera acid lava flows and silicic endogenous domes occupied the crater floor. Into this volcanic pile were intruded the subvolcanic granites, some of which contain fayalite, hedenbergite sub-alkaline and alkaline amphiboles and biotite. Also oversaturated syenites and syenomonzonites are a minor but important group of associated rock types, whilst basic rocks are found both predating and post-dating the granite magmas. The petrology of the granites and associated


Edge of sedimentary cover
YOUNGER GRANITE COMPLEXES
Granite and syenite
Porphyry ring dykes
Volcanic rocks
Basement Complex
9°
N I G E R
Daura
Matsena
13°
Kano
Dutse
Birnin Kudu
Shira
Kila-Warji
Fagam
Zaria
11°
Ningi
Banke
Tibchi
Liruei
Kudaru
Zuku
Kaduna
Rishi
Saiya
Shokobo
Rishua
Bauchi
Zaranda
Kwandonkaya
Amo
Buji
Jos
Kigom-Ganawuri
Jos-Bukuru
Kagoro
Sara-Fler
Nok
Ropp
Sha-Kaleri
9°
Benue Trough
Mada
Afu
0
50
100
150 km
7°

rocks has been well described by BUCHANAN *et al.* (1971), but whilst many of these granites are known to be the source of cassiterite, columbite and wolframite, little has been written on primary mineralization. Current research has shown that zinc also plays an important role not only as a dispersed element substituting in the ferromagnesian lattice sites in many of the granites but also forms sphalerite and genthelvite in mineralized veins. Zinc is more abundant than tin within the province and shows a much greater enrichment than tungsten or niobium in granites and mineralized veins. It also seems likely that the importance of tungsten in the Nigerian Province has previously been overstated.

To understand the Mesozoic mineralization related to the granites it is convenient to consider the peralkaline and peraluminous granites separately. It is not proposed to consider the evolution and origin of these rock types as this has been dealt with elsewhere. (BOWDEN and MARTIN, in prep.; BOWDEN and KINNAIRD, in press.).

Peralkaline Granites

The peralkaline albite riebeckite granites show a dispersed mineralization associated with recrystallization and formation of sub-solidus albite and microcline. They may also contain pyrochlore, chyolite and fluorite. The peralkaline granites, which are rather limited in distribution, confirm the abundance of zinc although no separate zinc mineral has been found. Whole rock analyses show up to 1.000 ppm. zinc which is concentrated in the amphiboles which may contain as much as 1% wt. ZnO (BORLEY 1976). In addition to these obvious increases in Na, Nb, F and Zn there is an enrichment in many other elements such as Zn, Th, Sn, Be, Li, Cs, Sb, Cd, Mo, Rb and Sr. Only five of these peralkaline granites occur in Nigeria and all are adjacent to, or near mineralized biotite granites.

Mineralization in Aluminous Granites

In contrast with the one dispersed phase of mineralization associated with the peralkaline granites, the biotite granites belonging to the aluminous trend show two distinct stages of mineralization:

1) The early dispersed phase of mineralization, in which columbite is an important mineral, affects the marginal and apical parts of biotite granite intrusions. It is an early postmagmatic stage which takes place during cooling and sub-solidus recrystallization. A textural change is effected by recrystallization, with new growth of microcline and albite, whilst columbite,

xenotime, thorite and Hf- and U- rich zircons are introduced. High columbite content coincides with high thorite content.

This stage of mineralization is represented by many of the fine grained biotite granites in the Nigerian Province, but the best known enrichment is found in localised parts of the Jos-Bukuru complex. The most extensive fine-grained granite within this complex in two narrow zones has given values up to 0.4% Nb_2O_5. (WILLIAMS *et al.*, 1956). Table I shows the abundance of Nb_2O_5 compared with SnO_2 in a series of samples taken by the writer from the granite.

TABLE I

Comparative Nb_2O_5/SnO_2 *values in samples from the Rayfield Gona Granite*

	ppm Nb_2O_5	ppm SnO_2		ppm Nb_2O_5	ppm SnO_2
88 A	90	25	10 D	900	520
88 B	770	200	10 E	2290	1450
88 C	510	165	10 F	1200	68
88 D	460	165	10 G	30	<20
88 E	470	70	10 H	1280	350
88 F	610	140	10 J	1720	430
88 G	55	50	10 K	750	360
88 H	470	130	10 L	500	20
88 J	770	50	10 M	1050	28
88 K	520	56	10 N	820	<20
88 L	1115	50	10 O	320	<20
88 M	590	120			
88 N	630	120			

2) The later phase of mineralization associated with the aluminous granites is late post-magmatic. It takes place after the host rock has recrystallized and consolidated and is displayed as mineralized replacement veins. Sphalerite predominates in these veins although cassiterite, pyrite, galena and chalcopyrite are also abundant. Monazite, arsenopyrite, genthelvite, pyrrhotite and molybdenite are also common though not abundant whilst siderite, greenockite, chalcocite, covellite, native copper, phenakite, bismuthinite and uraninite may also occur at one or more localities. The niobium of the previous phase is unimportant in this phase although high niobium values may sometimes occur in veins which cut granites with high niobium values (Table II).

Evidence from the Rishi area of the Saiya-Shokobo complex demonstrates that vein distribution is related to the marginal and apical parts of the biotite granite intrusions. Although, southwards where erosion has proceeded to deeper levels and where successive granite intrusions have tended to modify earlier contacts, replacement veins are less abundant and their relationship to the host rock is less obvious. The veins, which are primarily associated with biotite granites may also form in basement gneiss, fayalite granite and volcanics but have not been found in peralkaline granites.

The veins appear to form by a series of replacement processes which take place in a distinct sequence although in many cases the processes overlap in time and space.

The main replacement processes which have been recognised include argillic alteration, fluorization (chloritic alteration), sericitic alteration, greisenization and silicification. The order in which these stages occur has not been firmly established but preliminary evidence indicates that it may vary from the established order in other metallogenic provinces.

The argillic alteration which involves partial alteration of feldspars to clay minerals, although accompanied by a minor introduction of sphalerite, is not an important phase of ore development.

In contrast, the fluorization phase is the most important phase of ore development since the bulk of the sulphides and also monazite appear to be introduced at this stage. There is a direct correlation between fluorine content and ore concentration. In addition to the input of fluorine there is a significant increase in iron content from $< 2\%$ for the averave of biotite granites to over 20% in some veins. Increases of Zn, Cu, Pb, Li, Ce and As are also recorded and all form separate minerals except the lithium which is accommodated in the mica lattice. The original biotite of the host rock may be partially chloritised in these veins or may undergo replacement. Therefore, mineralized veins effected by the fluorization phase may contain — in addition to quartz, Fe-biotite or chlorite and abundant fluorite — sphalerite, cassiterite, galena, chalcopyrite, pyrite, monazite, genthelvite, greenockite, arsenopyrite, and molybdenite. No other alteration phases show such an abundance, or mixed assemblage of ores and locally these veins may become a solid sulphide mass exceeding 30 cm. across.

In the sericitic phase of alteration, which has minor amounts of associated sulphide minerals, only sphalerite, galena and cassiterite are common. The sericitic alteration which forms as a result of the breakdown of feldspars is very small in comparison with the degree that has been described in other provinces. The resulting sericite forms fine-grained aggregates with quartz and a little topaz.

Greisenization which is more common, results in the formation of veins containing unstrained quartz, large flakes of bright blue-green siderophyllite or less commonly, white protolithionite, with minor topaz. Cassiterite is the only ore mineral commonly associated and is often found within mica clusters as twinned and zoned crystals or as anhedral brown to colourless grains.

Chemically these veins show a wide range in composition but this is largely due to the percentage of siderophyllite within the rock. The varying siderophyllite content also affects the appearance of the vein in hand specimen and these may vary from almost white and fine-grained to a dark greeny-black often more coarsely grained rock. The two analyses below indicate this varying chemical composition.

Composition	White fine grained vein	Greeny black more coarse vein
	Sample 5 L Saiya Shokobo Complex	Sample 5 AL Saiya Shokobo Complex
SiO_2	90.9	54.2
TiO_2	0.1	0.1
Al_2O_3	1.2	9.7
Total Fe (as FeO)	3.4	27.3
MnO	0.05	0.31
MgO	<0.02	0.02
CaO	0.24	0.12
Na_2O	0.15	0.11
K_2O	0.81	5.85
SnO_2	0.14	0.88
ZnO	n. d.	0.10
	97.01	98.69
Li	760 ppm	4645 ppm
Be	2	6

Only a small amount of ore minerals are associated with the silicification phase of alteration but it is an important ore stage since it is with this phase that the wolframite is associated. Wolframite is generally only abundant in quartz veins in country rock marginal to the granites whilst for most of the mineralised veins within the granites the tungsten content is less than 4 ppm. Locally wolframite may be abudant as bladed crystals parallel or perpendicular to the strike of the vein but large areas of the quartz vein may also be barren. Misconceptions in past literature about the abundance of wolframite appear to be due to the poor identification of dark metallic-looking sphalerite with an enriched iron content.

Zinc mineralization is associated with a minor pegmatitic vein development, which appears to be very late stage. The zinc forms genthelvite ($Zn_3Fe\,Be_3Si_3O_{12}S$) which appears as brownish-red crystals up to 5 cms. across. The genthelvite is associated with albite/oligoclase quartz and rarely — with crystals of uraninite.

It is apparent that zinc is abundant at all stages of granite development. In the mineralized veins it occurs as sphalerite and genthelvite and in some instances the sphalerite content far exceeds the amount of cassiterite. The following table indicates the comparative values of tin, tungsten, zinc and niobium in some biotite granite samples and mineralized veins. Samples N58A and N58C are altered granite on either side of a mineralized vein — sample 58B. This vein is the only one contained within a granite complex that shows high tungsten values and this is believed to be related to the intrusion of a fine-grained biotite granite at depth.

TABLE II

Comparative tin, zinc, tungsten and niobium values in biotite granites, altered biotite granites and mineralized veins in Nigeria

	Sn	Zn	W	Nb	
N 75	40 ppm		4 ppm		biotite granite
N 77	110		4		"
N 91	25		4		"
N 92	50		4		"
N 94	25		4		"
N 58 A	160	292	1320		altered granite
N 58 C	100	331	720	180	"
N 58 B	350	2400	860	93	mineralized vein
JB 22	520	0.82 %	4	84	mineralized vein
JB 118 A	120	1.92	4	74	"
JB 64 H	1000	0.04	4	132	"
JB 120	200	40 ppm	4	249	quartz vein
SS 117	6150	0.1 %	40	122	mineralized vein
SS 2 C	330	0.65	12	500	"
SS 106 A	200	1.73	4	7	"
SS 102	850	1.68	4	7	"
SS 109 A	840	1.35	4	2	"
SS 109 C	190	2.16	8	2	"
SS 109 B	1.94 %	0.82	4	10	"

N = Liruei Complex. JB = Jos Bukuru Complex. SS = Saiya Shokobo Complex.

PART 2

MINERAL DESCRIPTIONS

Cassiterite

The Nigerian tin province is the world's sixth biggest producer of tin: cassiterite is the only tin mineral as yet recorded from the Mesozoic granites although nigerite has been recorded from the basement pegmatites. (JACOBSON & WEBB 1946).

Cassiterite occurs widely in the anorogenic granite province but because alluvial workings for the minerals are situated principally on the Jos Plateau, it has often been incorrectly assumed that tin mineralization is restricted to this small area in northern Nigeria. In fact similar styles of mineralization have been recognised in the majority of the Mesozoic granites in Nigeria and in petrographically similar, but chronologically older anorogenic granites in Niger.

Compositionally, cassiterite contains oxide impurities of Fe, Nb, Ta, Ti, Cu, Zn and Mn. An analysis of cassiterite from the Jos-Bukuru complex by Amalgamated Tin Mines of Nigeria showed the following composition:

SnO_2	89.50
Nb_2O_5	4.70
Ta_2O_5	1.60
Fe_2O_3	1.64
TiO_2	0.12
Sc_2O_3	0.01
Loss on ignition	3.30
	100.87

Cassiterite occurs as a minor constituent in many granites and is not confined to albitized variants. The values of cassiterite in a particular granite may vary from nothing to over 400 ppm. SnO_2 (Table I). In addition to these occurrences, abundant cassiterite, varying from small or large anhedral to perfect crystals which may exceed 1 cm. in size (Fig. 2), is found in mineralized veins throughout the province.

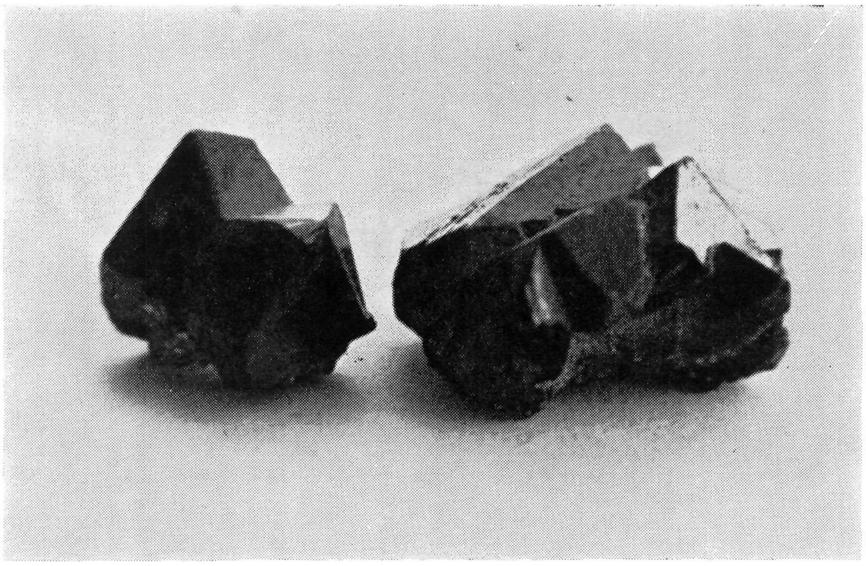


FIG. 2

Cassiterite crystal from a mineralized vein. Liruei complex

Cassiterite varies in colour according to its source, ranging from dark brown to black, occasionally crystals may show an adamantine lustre but more commonly it displays a sub-metallic lustre or it may be brown, friable and hackly. Translucent ruby, yellow and white varieties have been recorded and there is a small amount of colloidal wood tin from Gindi Akwati and south Ropp in the Ropp complex and from the Gaiya River in the Liruei complex.

Cassiterite occurs in several phases of mineralized veins. It is present in the sulphide assemblage associated with the fluorization phase of alteration (Fig. 3) and it occurs within and around micaceous clusters in greisens. Cassiterite has also been introduced in addition to wolframite in the silicification stage. In thin section the cassiterite associated with quartz veins or silicified veins is pale yellowish, brownish or colourless, whilst the cassiterite found associated with green mica in greisens is dark reddish brown in colour and may show zoning, from dark coloured at the centre to colourless at the margins. Some of this darker coloured cassiterite is intensely pleochroic from pale yellow to a dark reddish colour which may be attributed by many authors to a high niobium content.

Polished sections of cassiterite from the sulphide-fluorite rich veins show few, if any, inclusions, and those so far observed appear to be of pyrite. Inclusions in cassiterite from quartz veins at Ropp Adit are more numerous and so far seem to be solely quartz.

Some cassiterite is magnetic and ATMN * geologists have found that the

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* ATMN = Amalgamated Tin Mines (Nigeria) Ltd.

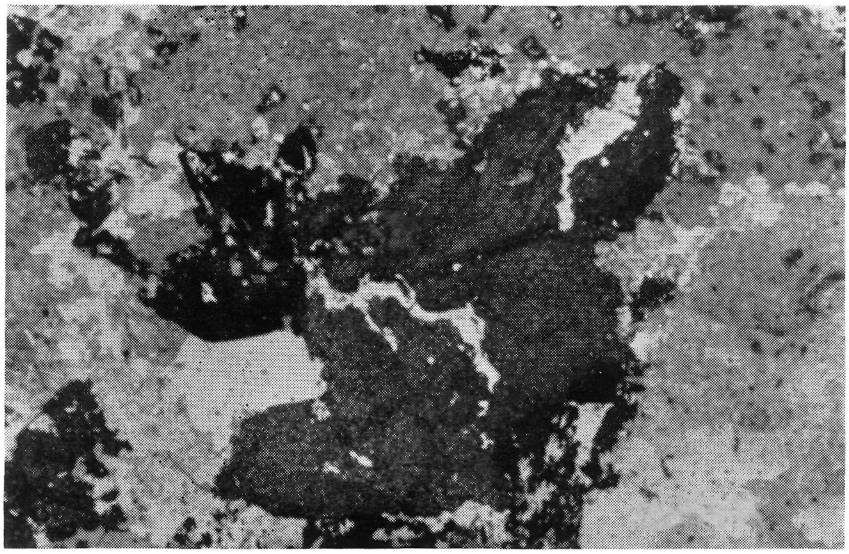

FIG. 3

Twinned cassiterite with chalcopyrite in a groundmass of quartz, fluorite and chloritised mica (Low power magnification).

magnetic quality does not vary with colour and that even transparent varieties may be magnetic. Unlike the cassiterite from the Australian localities described by GREAVES *et al.* (1971), the Nigerian magnetic tin is neither localised nor apparently restricted to certain rock types.

The bulk of cassiterite is won by alluvial mining since the accessory cassiterite in granites is not of high enough concentration to justify extraction costs. In localised parts of the Jos-Bukuru complex however, cassiterite forms a valuable by-product of columbite extraction from heavily decomposed albitised granites (Table I).

The way in which tin is transported in hydrothermal fluids appears to be in doubt although most workers agree that it is transported in fluids rich in chlorine and fluorine. Some advocate a Sn fluoro-hydroxyl complex (SHCHERBINA 1963, BARSUKOV and KURIL'CHIKOVA 1966) whilst HESP and RIGBY (1972) more recently have considered stannic chloride complexes to be more prevalent and therefore more stable. Shcherbina believes that Sn, W, Al, Li, Be, Y, Ti and Zr are fluorophile whilst Cu, Ag, Fe and Pb are chlorophile elements. However, as Part 1 indicates, in many of the Nigerian mineralized veins it is not uncommon to get cassiterite, sphalerite, galena and chalcopyrite together in one sample.

In the Nigerian model it is suspected that most tin partitions towards the aqueous chloride phase although this does not preclude the occurrence of some tin in the silicate-fluoride phase. At the time of writing there is little fluid inclusion data to support this hypothesis.

Columbite and associated minerals

Nigeria is the world's leading producer of columbite and whilst there is a small production of pegmatitic columbo-tantalite from the basement, the vast bulk of the material is won from elluvial and alluvial deposits associated with the Mesozoic fine grained biotite granites.

Columbite is known to occur in varying quantities in all complexes where fine-grained biotite granites occur, the best-known enrichment being that found in localised parts of the Jos-Bukuru complex (Fig. 1). From an early date it was known that some granites within this complex contained more columbite than others and MacLeod (1956) and Williams *et al.* (1956) analysed all the granites and found that only the Rayfield-Gona, which is the principal fine-grained biotite granite, contained economically significant values. These values ranged between 150 and 2.875 ppm. Nb_2O_5 and in two narrow zones varied between 760 ppm. and 0.4%. An analysis of fifty samples by the author from two different areas produced values which ranged up to 2.290 ppm. Nb_2O_5 and some of these results were presented in Table I. There appears to be no correlation between high columbite and cassiterite content but it appears that high columbite content coincides with a high thorite content.

The columbite occurs as small, black opaque crystals which are variable in shape from platy to acicular. It is rarely coarser than 20 mesh — the greater portion lying between 60 and 200 mesh.

Columbite from the Mesozoic granites, in contrast to that from the basement, is more niobium rich. An analysis of this columbite from the granites shows an $Nb_2O_5 : Ta_2O_5$ ratio of 8 : 1. In contrast, analyses of columbo-tantalite from basement pegmatites show a whole range of the isomorphous series.

Analysis of Columbite from Harwell

Nb_2O_5	64.8 %
Ta_2O_5	8.1
FeO	15.1
Sc_2O_3	0.02
TiO_2	0.49
Mn_3O_4	1.95
ZnO	0.15
SnO_2	1.60
U_3O_8	<0.05
Loss on ignition	1.40
	93.66

Thorite, xenotime and hafnium-bearing zircon are commonly found associated with the columbite as accessory minerals within the granite and MacLeod (1971) also records pyrolusite and anatase in association.

Sphalerite

In contrast to previous literature on Nigerian mineralization it has been found by the writer that sphalerite is the dominant mineral of the hydrothermal mineralization phase and occurs to a greater or lesser extent in several of the alteration phases recognized by the writer. It may occur in masses 30 cm. across, especially in the fluorization phase of alteration. In massive form it varies from reddish brown to almost black with a resinous to submetallic lustre.

In thin section it shows characteristic dodecahedral cleavage and varies in colour from light yellow to orange or deep blood red. Deer, Howie and Zussman (1969) suggest that the different colours of sphalerite may be associated with certain elements, in particular that tin may be responsible for the red colouration, but increase of iron may mask this red colouration. In dark coloured sphalerites with a metallic lustre, the iron content varies from 6.5-10% with corresponding zinc values of 52.5 and 69.9%. Cadmium content decreases with increasing iron content. Analyses of two dark metallic looking sphalerites are shown below:

	Rishi		Liruei
Cu	4.21 %		0.25 %
Pb	0.14		0.96
Zn	52.5		60.9
Fe	10.2		6.48
Mn	0.02		0.04
Cd	0.19		0.59
Co	137 ppm		< 16 ppm
Ag	61 ppm		5 ppm
S ≡ Cu	2.05	S ≡ Cu	0.12
S ≡ Zn	24.87	S ≡ Pb	0.14
		S ≡ Zn	28.85
S ≡ Fe	5.66	S ≡ Fe	3.59
	99.84		101.92

The Rishi sphalerite is associated with the fluorization stage of alteration whilst the sample from Liruei comes from a vein affected mainly by greisenisation and silicification. The Rishi sphalerite contains 3.5% more Fe than the Liruei sample but part of it is contained within the exsolved chalcopyrite. Occasionally both red and yellow varieties occur in the same thin section, the former occurring as large anhedral patches with exsolved cubes of chalcopyrite along the cleavage, whilst the latter occurs as rims around patches of chalcopyrite. It seems likely that there are several phases of sphalerite formation: an early well crystallised, uniformly grey phase and a later slightly darker phase full of blebs of chalcopyrite. Polished sections of sphalerite show inclusions of chalcopyrite, molybdenite and replacement of galena. The blebs of chalcopyrite are attributed to exsolution on cooling from a higher temperature ZnS-$CuFeS_2$ solid solution.

In sulphide rich veins associated mainly with the fluorization stage of mineralization, and to a lesser extent the sericitic stage, sphalerite occurs in association with cassiterite, galena, pyrite, chalcopyrite, molybdenite, greenockite, chalcocite, covellite, bornite, monazite and genthelvite (Fig. 4 and 5). However in greisens it is associated with cassiterite, and occasionally galena and chalcopyrite.

In replacement veins that show some crude zoning, the sulphide-rich portion generally occurs towards the centre of the vein. However, in a section of one of the greisens of the Liruei lode sphalerite occurred marginally.

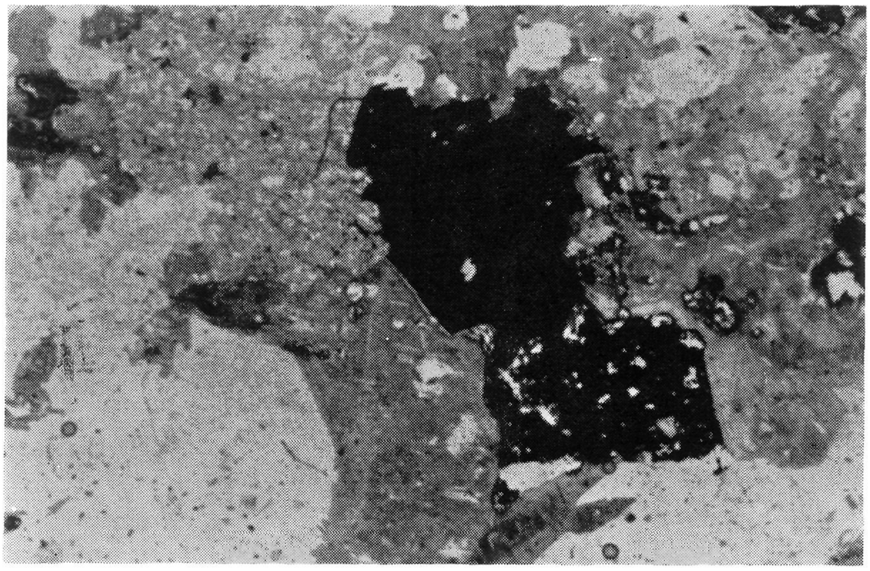

FIG. 4

Sphalerite full of inclusions adjacent to molybdenite (opaque centre). Cassiterite (partly visible top right) is also abundant. The groundmass is composed of blue-green siderophyllite, quart, fluorine and siderite (Low magnification)

Only recently has sphalerite been identified in large quantities. It does not survive as an alluvial mineral and since the attention paid by the mining companies to primary mineral veins has been small on account of uneconomic tin values, the abundance of sphalerite remained unrecognised. It has been observed and described by the writer from veins in several widely-spaced complexes while at Liruei, Ririwai Mines Ltd. estimate that the ratio of Zn to Sn in a lode currently being mined is 3 or 4:1.

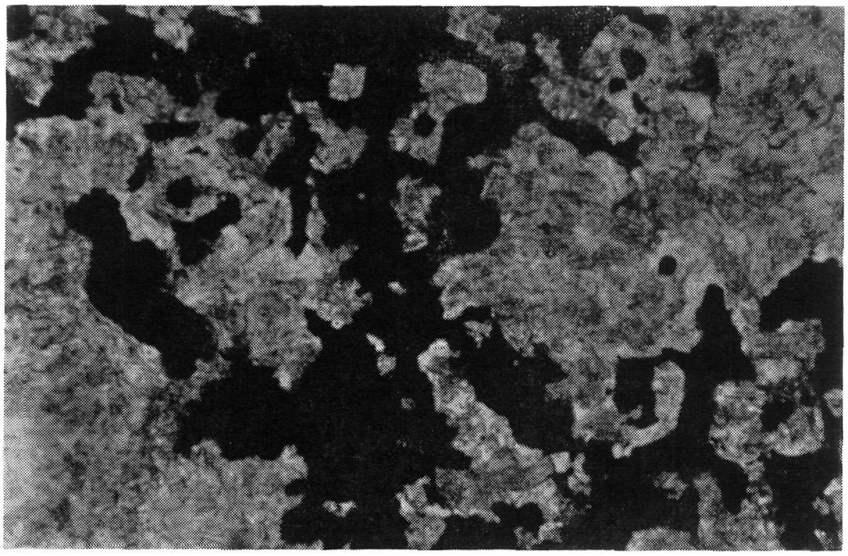

FIG. 5

Sphalerite veinlet, 2 mm in width, cutting a mineralised vein consisting of quartz, fluorite and chloritised mica

Chalcopyrite and other copper minerals

Chalcopyrite is the most common copper mineral and is widely distributed in replacement veins. It may be exsolved along cleavage traces in sphalerite, it may form rims around sphalerite and other minerals, or it may occur in massive form.

Chalcopyrite is not as abundant as some of the other sulphides and is only abundant in the fluorite-rich replacement veins although it may be found in minor quantities in other veins.

Very small amounts of other copper minerals may be associated with the chalcopyrite. Bornite has been identified in some of the veins in the Rishi area and chalcocite and covellite have been observed in polished ores. Native copper was found in altered pyroxene granite at the adit in the Ropp Complex (Fig. 1) whils azurite, malachite and chalcanthite have been found as secondary copper minerals.

In polished sections, chalcopyrite may contain silicate gangue in the form of streaks and blebs and may show minor replacement by chalcocite at its margin. A very characteristic feature observed in the Nigerian polished ores is the blebs of chalcopyrite occurring as trains or in an irregular fashion within sphalerite. Those from Dawa show that chalcopyrite is most abundant in sphalerite near its margins.

Molybdenite

Small flakes of molybdenite are common in mineralized veins and altered granite, but the only large scale occurrence is in riebeckite-aegirine granite in the Kigom Hills. The molybdenite is scattered through the granite in rich clusters several centimetres across and in small disseminated flakes; it also forms a coating on joint surfaces.

Most commonly small quantities of molybdenite occur in veins, or in veins and adjacent altered granite. The molybdenite in the veins is in association with cassiterite, sphalerite, galena and copper minerals at Ropp, and with a similar assemblage and has been proved to a depth of 20 metres. The vein follows a fine-grained granite porphyry dyke, presumed to be of younger granite age. The galena which contains 0.5% silver has been found at depth in cubes as large as 15 cm. across but usually occurs as cubes less than 5 mm. in size. The maximum width of the galena-bearing vein is recorded by BUCHANAN *et al.* (1971) as 20 cm. but the vein rapidly pinches and swells and often dies out altogether further along the strike.

A galena-rich vein is also known to occur in the south Ropp area 1.5Km.-west of the outer ring-dyke. It is 30 to 45 cm. wide and strikes 325°, parallel to the ring-dyke.

Galena appears to be associated with a slightly later stage of mineralization than the bulk of the sphalerite, chalcopyrite and pyrite. However, in the polished section from the west of the Liruei lode there is evidence to show that galena is being replaced by chalcopyrite and sphalerite which indicates that one of the phases of sphalerite formation described earlier has formed after the galena of the lode.

Greenockite (CdS)

Greenockite has been identified in one of the replacement veins from the basement near Dutsen Rishi. It was identified on an X ray scan of a thin section and shown to occur as discrete grains and not as a coating on sphalerite, although sphalerite does occur in other parts of the vein. It is associated with choritised mica, chalcopyrite, monazite, fluorite and cassiterite. An analysis of sample 103 showed a cadmium content of 150 ppm. Greenockite has also been recorded from the Kaffo valley albite-riebeckite granite at Liruei (BUTLER & THOMPSON 1970). It is in the form of thin yellow disseminations and patches on quartz and feldspar and is not associated with sphalerite since the only zinc bearing mineral in the granite is riebeckite. These authors considered that the greenockite as evidence of a later mineralisation than the albitisation. The writer considers therefore that greenockite has been introduced as a result of the intrusion of the adjacent Liruei biotite granite.

Bismuthinite

As yet bismuthinite has only been identified in the Liruei Complex, where it has been found underground in the mine recently initiated to exploit the Liruei lode. It has been found growing in vugs in association with cassiterite and clay minerals and forms long fragile, slender greyish needles, with a metallic lustre, up to 10 cm. long.

Fluorite

Fluorite forms a common accessory mineral in many of the biotite granites and is colourless or pale green. It is also abundant in replacement veins, where it is predominantly colourless with occasional deep purple patches.

Both topaz and fluorite may occur in the same rock sample although the two minerals are never abundant when co-existing. Abundance of one appears to preclude the other.

There appears to be a direct correlation between ore concentration and fluorite content. Highest enrichment in sulphide ores, particularly of sphalerite, pyrite, arsenopyrite and chalcopyrite are always associated with fluorite-rich chloritised veins.

Topaz

Topaz may occur in association with beryl and quartz in the marginal pegmatitic vugs of some biotite granite. Crystals 7.5 cm. long have been collected from the Tega granite of the Amo complex (Fig. 1) in the Timber Creek area. They have also been found *in situ* in the Juga area of the Kwandonkaya complex and have been found in the river gravels ot the Ganawuri and Jarawa Hills.

The topaz is usually colourless but blue-green, yellowish and brownish varieties have been found. It is rarely of gem quality but should prove useful for fluid inclusion techniques.

Very fine-grained topaz also occurs in replacement veins formed by the breakdown of feldspar into sericite, topaz and quartz.

Topaz is a constituent of the greisen phase of alteration in addition to forming an accessory in the sericitic phase, although the topaz content is small in comparison with the amount in greisens from Czechoslovakia (BAUMANN *et al.*, 1974) or Alaska (SAINSBURY 1960). The individual topaz grains are small rarely forming greater than 1 mm. in size.

In contrast to the fluorite rich veins however, topaz-bearing veins contain cassiterite with only minor sulphide minerals. In thin section it appears as small colourless anhedral grains associated with either sericitic or siderophyllite mica.

Zircon

Zircon is a common accessory mineral in many of the younger granites. It occurs in two forms:

1) In the metamict state it may be associated with xenotime, thorite, and columbite in the late stage albitised granites and with pyrochlore and other minerals in the albite riebeckite granites. In the former the zircon may contain up to 5% Hf and when Hf is present to this extent the mineral is in the form of almost opaque brown grains and is usually uraniferous — this is the variety described as malacon. Some of the metamict zircon in anomalously magnetic and MacLeod and Jones (1955) showed that this is due to a high proportion of loosely combined iron. The degree of magnetic permeability is thought to be controlled by the relative proportions of non-magnetic Fe_2O_3 and magnetic Fe_3O_4 in the mineral. It is probable that cyrtolite is also present in the albitised granites and albitites but there is difficulty in recognition of the mineral since both cyrtolite and malacon contain uranium and thorium in addition to rare earths, Hf and water. Also, both minerals are metamict. CARUBA *et al.* (1975) believes that in certain cases metamict zircons arise from normal hydroxyled zircons that have crystallised out of a medium rich in fluorine and radioactive elements and that fluorine leads to the substitution $(SiO_4)^{4-}$ $(OH)^{-}_{4}$. This leads to weaker bondings causing the lattice to be vulnerable to the particles given off during the decay of radioactive elements.

2) In contrast, the zircons from other granite sources are colourless, brownish yellow to amber or grey and are transparent to sub-translucent. In the Jos/Bukuru complex, WILLIAMS *et al.* (1956) describe their technique for differentiating various granite types by the zircon colour. This method of granite identification is sometimes useful where the granite is badly weathered and decomposed.

Thorite

Thorite is found in the late-stage albitised granites in close association with columbite. It occurs as anhedral, resinous grains averaging 1 mm. in size and they have either a reddish brown or orange (variety orangite) colour. There seems to be a direct proportional relationship between thorite and columbite content and visible thorite is a good indicator of high columbite content.

The thorite collected from the Harwell area of the Jos-Bukuru complex is strongly radioactive as a result of the replacement of some of the thorium by uranium giving the variety uranothorite. Because of the radioactive content the thorite is in a metamict state.

Thorite and zircon appear to form a structural series and it appears that there is a definite trend from zircon, malacon (a uranium-thorium zircon) and cyrtolite (a thorium-uranium zircon) to thorite.

PETROVA (1961) records replacement of malacon by thorite in Siberian albitites and evidence from a limited number of Nigerian thin sections indicates that a similar phenomenon takes place. In the zones in malacon that have become isotropic, point-like aggregations which discolour the metamict malacon unevenly in shades of brownish red are suggested by Petrova to be ferrothorite. Petrova presumes that the development of isotropic properties in malacon is associated with the activity of thorium during replacement of the mineral by thorite.

Beryl: Genthelvite: Phenakite: Danalite

Beryllium minerals, although not common, occur in mineralised veins and pegmatites in many areas of the Mesozoic granite province. Most occurrences are situated in the northern part of the province where granitic members of the ring complexes are exposed at or near their upper contact with pre-existing rocks. Southward where erosion has proceeded to deeper levels beryllium mineralisation is less conspicuous.

Beryl has been recorded from numerous localities, most notably in the pegmatites in the Tega biotite granite of the Amo complex, near the contact with the Teria biotite granite. Aquamarine can occasionally be found there in association with large colourless topaz crystals. Aquamarine has also been found in a pegmatitic vein in the Kulfana biotite granite of the Kwandonkaya complex — again from a contact facies.

The mineral genthelvite appears more common than beryl. It has been noted in the Dawa-Rishi area of the Saiya-Shokobo complex where it is usually restricted to mineralized veins in biotite granites less than 30 metres from their contacts it has also been described by von Knorring and DYSON (1959) from the Harwell area of the Jos-Bukuru complex and by Berridge in BUCHANAN *et al.* (1971) from the Jarawa Hills.

Genthelvite, resembling massive almandine, appears as a late stage replacement mineral in the albitised granite at Harwell and the following description is given by von Knorring and Dyson (op cit). «In the locality it occurs as irregular knots and veins up to 18 cm. across within an irregular vein of almost pure albite. Commonly, these knots consist of pure genthelvite, but may contain stumpy laths of albite. A selvedge of protolithionite from 0.5-2 cm. thick with accessory thorite frequently crystallised as a peripheral growth on euhedral genthelvite». They also describe genthelvite in microcline pegmatitic veins as anhedral masses up to 5 cm. across. In thin section the genthelvite is greyish or very pale pink and isotropic. It may be almost pure genthelvite or may be intimately intergrown with albite. Some triangular sections occur and the mineral is intersected by numerous cracks. It has inclusions of columbite, zircon and cassiterite and occasionally orangite in the specimens studied by von Knorring and Dyson (op cit). A chemical analysis of the mineral from Harwell (von Knorring and Dyson, op. cit.) shows that it is very similar in composition to that from silicified syenites from U.S.S.R. described by GURVICH *et al.* (1963). The Harwell sample showed 12.9% BeO compared to 11.9% in the genthelvite analysed by Gurvich and 40.56% Zn compared to 41.3% Zn. The formula for the Harwell genthelvite is:

$$Zn_3FeBe_3Si_3O_{12}S$$

In the sample described by Gurvich the associated minerals are willemite, fluorite, cyrtolite, tantalo-columbite and other minerals.

An analysis of genthelvite from the Ladini area of the Saiya-Shokobo complex showed greater Fe and Mn content than the Harwell sample, and a corresponding decrease in zinc content, although the zinc is still predominant so the name genthelvite still applies.

GURVICH *et al.* (1963) believe that genthelvite forms in the late stages of mineralisation as a result of pneumatolytic processes leading to the formation of quartz veins and silicification. The circulating solutions were rich in Si, S, Be, Zn and other cations (Fe, Mn, Pb, and Mo) and were poor in alumina; as KALENKOV (1959) has shown, that in the absence of Al genthelvite will form instead of beryl.

BEUS (1956, 1962) describes occurrences of genthelvite similar to those in the younger granite province of Nigeria. He believes that in granites which consolidate at comparatively high in the crust and where the formation of mineralised pegmatites is restricted, such Be as is present will precipitate

Analyses of Genthelvite

	Harwell		Ladini
SiO_2	30.70		31.5
TiO_2	n. d.		0.1
Al_2O_3	0.18		n. d.
FeO	11.73		23.7
MnO	1.72		3.1
BeO	12.39		12.2
ZnO	40.56		25.5
MgO	tr.		0.04
CaO	tr.		0.08
Na_2O	tr.		0.15
K_2O	n. d.		0.07
S	5.50		5.00
	102.78		101.00
$O \equiv S$	2.74	$O \equiv S$	2.49
	100.04		98.51
Li	n. d.		400 ppm

in a hydrothermal-pneumatolytic environment. He concludes from the available data that formation of high concentrations of Be in the hydrothermal process coincide in time and space with the formation of high concentrations of tungsten, tin and molybdenum. Some of the veins at Dawa contain genthelvite, cassiterite and molybdenite but no genthelvite-tungsten association has been found here yet.

Danalite ($Fe_4[Be_3Si_3O_{12}]S$) has also been identified by TAYLOR (1959) from the Dawa area; it is dark red with a slightly greasy lustre and in thin section is pale pink. He quotes the specific gravity as 3.44 and R.I. as 1.754. X-ray spectroscopic analysis showed Fe as the major constituent with subordinate zinc and minor manganese with a trace of chromium. BeO content is given as 13.0%.

Phenakite (Be_2SiO_4) has been found by TAYLOR (1961) in small amounts in greisens from the Ladini-Dawa area of the Saiya-Shokobo complex in association with cassiterite, topaz, fluorite, danalite and sphalerite; it has also been recovered from crushed ore and from alluvials in the same area.

Further investigations of mineralised veins both in hand specimen and thin section will probably show that beryllium minerals are even more widespread.

Mica

The mica in the Nigerian Younger Granite Province belong to two related tri-octahedral series. There are only small amounts of dioctohedral micas in the granites and these usually take the form of sericite, derived from the alteration of feldspars during successive stages of replacement vein formation.

Micas have been analysed from biotite granites, albitised granite and replacement veins (Table III). The results have been plotted on a triangular diagram devised by LANGE *et al.* (1972) and the structural formulae have been calculated using the method of FOSTER (1960).

The magnesium content of nearly all the micas is extremely low and the biotites are therefore characterised by a high Fe^{2+}/R'' ratio which is greater than 0.94 except for the biotite from Sara Fier (Table III) where the ratio is 0.78. The Fe^{3+}/R''' ratio is also high:

$$(R'' = Mg + Fe^{2+} + Mn) \; (R''' = Al^{vi} + Fe^{3+} + Ti^{4+}).$$

In the aluminous granites the micas are iron rich and belong to the phlogopite → annite series. During the processes of replacement vein formation there is a progressive alteration of the micas and they become enriched in alumina and lithium; those micas belong to the siderophyllite → protolithionite → zinnwaldite series. Thin sections show that during alteration there is a progressive destruction of the brown iron-rich annitic mica of the granite and a replacement by chlorite, with the growth of new blue-green siderophyllite which in turn may be overgrown or partly replaced by pale green, grey or almost colourless protolithionite. Early breakdown of feldspars releases potassium which forms sericite and related minerals. This sericite forms small clustered grains at first marginal to, or within the feldspar and then completely replacing it. The sericite itself may further be altered and break down to give silica with released potassium and aluminium. Perhaps some is transformed to tri-octohedral mica, since in the latest stages of replacement only blue-green siderophyllite or colourless protolithionite is found. Thin section comparisons of mica-rich greisens and host biotite granite reveal that not all the siderophyllite can have formed at the expense of the original annitic mica. Thus, late-stage mica formation, derived from sericite enriched in lithium and iron by volatiles, seems likely.

During the early dispersed phase of mineralization in the biotite granites the albitization, which affected the perthites, is accompanied by a modification of the micas. The biotites become enriched in alumina and lithium and depleted in Fe, and protolithionite appears to be the ultimate composition.

TABLE III

Analysis of the micas from some of the granites

	1	2	3	4	5	6	7
SiO_2	35.94	33.10	35.36	30.72	35.14	37.58	37.38
Al_2O_3 ...	11.71	9.77	10.90	11.54	6.44	15.43	11.89
Fe_2O_3 ...	5.00	12.19	3.76	11.62	4.40	4.96	4.38
FeO	23.91	24.48	31.38	26.49	34.92	25.00	28.65
MgO	6.35	1.95	1.06	0.15	0.43	0.32	0.22
CaO	1.65	2.37	n.d.	1.70	0.97	1.15	0.16
Na_2O ...	0.42	0.41	0.97	0.44	0.74	1.67	0.39
K_2O	6.95	5.43	9.04	4.35	8.92	7.34	8.78
H_2O^+ ...	4.15	5.55	3.74	8.27	3.12	—	1.84
H_2O^- ...	0.03	1.94	n.d.	0.27	0.06	0.52	0.67
TiO_2	3.33	2.96	3.04	3.04	2.87	1.42	1.84
P_2O_5	nil	nil	nil	0.06	0.03	tr.	n.d.
F	n.d.	n.d.	n.d.	n.d.	n.d.	2.01	4.36
MnO	0.50	0.64	0.65	0.64	0.53	0.20	0.41
Li_2O	n.d.	n.d.	n.d.	n.d.	n.l.	—	0.77
	99.94	100.55	99.90	99.29	101.04	101.85	97.60
Less O..					1.04	1.86	
					100.00	99.99	

Formula calculated to 24

	1		2		3		4		5		6		7	
Si	5.616	8.0	5.282		5.798	8.0	4.744		5.984	7.72	6.05	8.0	6.03	8.0
Al	2.156		1.842		2.107		2.106		1.274		1.95		1.97	
Fe’’’	0.228		0.876		0.095		1.150		0.544		—		—	
Al	—	4.418	—	4.728	—	5.395	—	4.10	—	5.452	0.98	5.26	0.29	5.51
Ti	0.392		0.354		0.374		0.352		0.362		0.17		0.22	
Fe ’’’....	0.360		0.588		0.368		0.202		—		0.64		0.53	
Fe’’	3.124		3.268		4.303		3.428		4.912		3.36		3.86	
Mn	0.066		0.054		0.091		0.084		0.074		0.03		0.06	
Mg	1.476		0.464		0.259		0.034		0.104		0.08		0.05	
Li	—		—		—		—		—		—		0.50	
Ca	0.276	1.690	0.406	1.638	—	2.201	0.284	1.268	0.172	2.320	0.20	2.23	0.01	1.94
Na	0.128		0.126		0.309		0.128		0.240		0.52		0.12	
K	1.286		1.106		1.892		0.856		1.908		1.51		1.81	
OH	4.328		5.902		4.091		8.544		3.498	4.798	3.01		1.98	4.20
F	—		—		—		—		1.300		—		2.22	

1. Fe-biotite from Fier hastingsite biotite granite, Sara Fier. Nigeria.
2. Lepidomelane (Foster) from Kula hastingsite biotite granite, Pankshin.
3. Annite from early hastingsite biotite granite, Amo.
4. Lepidomelane taken from Daffo hastingsite biotite granite, Sha Kaleri.
5. Annite taken from riebeckite biotite granite, Amo.
6. Li-siderophyllite from Kudaru biotite granite. Analysis taken from Bain (Jacobson, 1947).
7. Li-siderophyllite from Liruei biotite granite. Source of data 1-5, 7, BUCHANAN *et al.* (1971).

TABLE III (contd)

Analysis of the micas from greisens and pegmatitic veins

	8	9	10	11	12	13
SiO_2	39.2	36.10	45.50	41.11	42.24	43.60
Al_2O_3	12.24	13.26	10.42	16.59	19.62	19.09
Fe_2O_3	2.98	7.29	2.48	2.00	2.02	2.57
FeO	29.0	25.30	28.10	22.61	18.64	14.80
MgO	0.03	0.05	0.13	0.13	0.08	0.10
CaO	0.15	0.20	0.40	n.d.	0.11	0.21
Na_2O	0.10	0.11	0.10	0.16	0.14	0.18
K_2O	8.15	8.82	6.09	9.92	8.84	9.54
H_2O^+	2.28	1.40	2.50	1.12	2.35	4.58
H_2O^-	1.61	1.27	1.56	0.29	0.48	0.82
TiO_2	2.58	3.07	2.47	0.30	0.18	0.88
F	—	—	—	5.49	5.02	—
S	—	—	—	—	0.02	—
MnO	0.43	0.51	0.40	0.67	0.30	0.84
Li_2O	1.40	2.73	1.96	1.85	1.90	3.34
	99.57	100.27	98.87	102.24	101.94	98.93
Less O				1.85	2.11	
				99.93	99.83	
Be	6 ppm	16 ppm	19 ppm			32 ppm
Cr	10 ppm	20 ppm	30 ppm			10 ppm
Zn	1660 ppm	2510 ppm	3140 ppm			1350 ppm
Cd	6 ppm	10 ppm	30 ppm			< 6 ppm

Formula calculated to 24

Si	6.36	8.00	5.74		6.96	8.00	6.30		6.22	8.00	6.16	
Al	1.64		2.26		1.04		1.70		1.78		1.84	
Al	0.69	6.30	0.22	6.71	0.84	6.31	1.30	5.72	1.62	5.33	1.34	5.4
Ti	0.31		0.37		0.28		0.03		0.02		0.09	
Fe'''	0.39		0.93		0.30		0.23		0.22		0.29	
Fe''	3.93		3.36		3.60		2.90		2.29		1.75	
Mn	0.06		0.07		0.05		0.09		0.04		0.10	
Mg	0.01		0.01		0.03		0.03		0.02		0.02	
Li	0.91		1.75		1.21		1.14		1.12		1.90	
Ca	0.26	1.98	0.03	1.85	0.07	1.29	—	1.97	0.01	1.71	0.03	1.8
Na	0.03		0.03		0.03		0.03		0.04		0.05	
K	1.69		1.79		1.19		1.94		1.66		1.72	
OH	2.47		2.80		2.55		1.15	3.81	2.30	4.63	5.09	
F	—		—		—		2.66		2.33		—	

8. Li-siderophyllite from greisen in Rishi biotite granite, Saiya / Shokobo Complex. Analysed by R. Batchelor, St. Andrews.
9. Li-Fe-siderophyllite from pegmatitic vein in Rishi biotite granite. Analysed by R. Batchelor.
10. Li-siderophyllite from greisen in Rishi biotite granite, Saiya / Shokobo Complex. Analysed by R. Batchelor, St. Andrews.
11. Protolithionite from Rayfield Gona granite, Harweg area, Jos / Bukuru Complex. Analysed by von Knorring and Dyson (1959).
12. Protolithionite from greisen in biotite granite, Liruei. Analysis taken from Bull. 32 of Geol. Survey. (BUCHANAN *et al.*, 1971).
13. Protolithionite from quartz-mica pegmatitic vein, Sabon Gida South biotite granite, Jos / Bukuru Complex. Analysed by R. Batchelor, St. Andrews.

Physical properties

The annitic micas in thin section are pleochroic from dark green, brown or reddish brown to light brown, straw yellow or pale green with Refractive Indices of 1.65 to 1.68.

Micas which plot in the siderophyllite field are very dark green, almost black, in hand specimen, and in thin section are pleochroic from dark blue-green to pale green, straw yellow or almost colourless (Fig. 6). NOCKOLDS and RICHEY (1939) give Refractive Indices of 1.582-1.625 for similar micas. These are low refractive indices for iron-rich micas and the authors believed that this is partly due to the low amount of ferric iron and partly to the presence of relatively abundant fluorine which constitutes 2%.

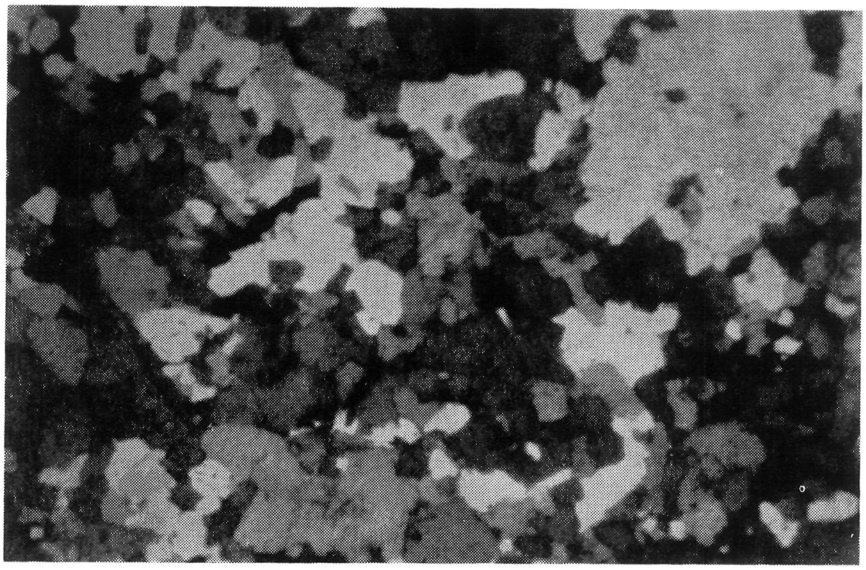

FIG. 6

Blue-green siderophyllite with cassiterite and large quartz grains in a greisen from the Saiya-Shokobo Complex. × *20*

The micas in the protolithionite field range in hand specimen from a pale blue-green colour (i.e. those near the protolithionite/siderophyllite boundary) to colourless. In thin section they may be pleochroic from very pale green to colourless or they may be grey to colourless with no pleochroic scheme. Von KNORRING and DYSON (1959) give one refractive index of 1.612 for protolithionite.

Chemistry

The annitic micas are rich in both Fe^{3+} and Fe^{2+} and during albitisation or replacement vein formation there is a gradual decrease of Fe^{3+} together with a marked decrease of Fe^{2+} and Ti between siderophyllite and protolithionite. There is also a gradual decrease of Na and a slight decrease of Mg although the Mg content is initially low. Variations in trace element proportions have yet to be investigated although preliminary evidence suggests that along the trend lithium-iron biotite → siderophyllite → protolithionite, there is a gradual increase in Zn and Be.

Considering the compositions of the iron-rich biotites from non-albitised granites it appears that they are relatively poor in Al_2O_3 since their values are generally less than 12%. In contrast, the micas from the albitised granites and replacement veins have Al_2O_3 values which exceed 12%. These micas also contain more Al^{3+}, Fe^{3+}, Ti^{4+} ions than those from the nonalbitised granites.

It is possible that the relative proportions of TiO_2 and Fe_2O_3 influence the colour. HAYAMA (1959) has shown that TiO_2, which is responsible for brown or red colour, is in general in very small amounts in greisen biotites. The green colour may also result from a high proportion of Fe_2O_3 to an average value of TiO_2.

Microprobe analysis (C. Abernethy pers. comm.) across a zoned mica, with a brown core and colourless zone followed by a green rim and white overgrowth, showed a progressive decrease, from the centre, in total iron and titanium, with increased aluminium.

It is concluded therefore that primary biotites from the perthitic granites are rich in «annite» whilst the composition of green or white biotites characterising the albitised granites is comparable to the biotites from mineralised replacement veins and these range between siderophyllite and protolithionite. FABRIES and ROCCI (1965) have also reached similar conclusions about the biotites from the Tarraouadji massif in the Niger Republic.

Further work on mica composition is intended, especially using microprobe analyses, to study the trace element distribution between micas from perthitic granites, albitised granites and mineralised veins.

Xenotime/Monazite

These rare earth phosphates have been mistakenly considered in the past to have the same paragenesis. However, the present study has shown that xenotime (yttrium phosphate) belongs to the early phase of mineralization in aluminous granites whereas monazite belongs to the later phase.

Monazite, a cerium phosphate, has been identified as a euhedral mineral in altered veins predominantly associated with the chloritic stage of alteration in the Rishi area. Xenotime has not been observed by the writer. Analyses of the two minerals for ATMN produced widely differing results at different laboratories — the following analyses are an average of these results.

	Monazite	Xenotime
P_2O_5	26.7	26.9
SiO_2	—	1.5
Fe_2O_3	—	0.48
Y_2O_3	1.45	28.9
La_2O_3	11.8	—
CeO_2	29.6	—
Pr_6O_{11}	4.1	—
ZrO_2	—	1.08
Nd_2O_3	9.4	0.23
Sm_2O_3	0.95	0.64
Gd_2O_3	1.2	1.24
Tb_4O_7	—	0.64
Dy_2O_3	0.39	6.15
Ho_2O_3	—	1.5
Er_2O_3	—	6.55
Tm_2O_3	—	1.55
Yb_2O_3	—	12.7
Lu_2O_3	—	1.55
U_3O_8	0.32	0.2
THO_2	5.45	0.94
Loss on ignition	4.8	1.7
	96.16	94.45

In thin section, monazite forms colourless to greyish euhedral crystals which are generally less than 0.01 mm. and commonly forming rosettes of crystals, but may reach 3 mm. in size. It has a very high relief and generally has strong to very strong birefringence with upper third or lower fourth order interference colours. Cross sections of the crystal (Fig. 7) have a very weak birefringence.

Two directions of cleavage are clearly visible in the few anhedral patches of monazite. In hand specimen the monazite is seen as small irregular reddish brown patches with a resinous-greasy lustre.

Wolframite

Wolframite has rarely been identified in mineralized veins within the Younger Granite complexes and analyses generally show less than 40 ppm

FIG. 7

Euhedral monazite set in a matrix of fluorite, quartz and chloritised mica with a large anhedral isotropic sphalerite adjacent to the monazite. × *30*

W within such veins. Instead it usually occurs in quartz veins in Basement granite or gneiss, usually within 1 Km. of a younger granite contact. Within each of these veins the distribution of the wolframite is most irregular. It may be found at the centre of the quartz vein or marginal to it, and the bladed crystals may be parallel or perpendicular to the strike of the vein. Wolframite is locally abundant but large areas of the quartz vein are barren which makes any comparison of relative tungsten values very difficult. The wolframite is commonly found on its own, although it may be accompanied by cassiterite.

The wolframite-bearing veins are usually vertical or subvertical and vary considerably in width. Occasionally, as in the Rishi area, they form a parallel series *en échelon.*

In the Durumi area of the Ropp complex, wolframite with cassiterite occurs in basement in a vertical quartz vein 23 cm. wide trending north-south over a distance of 200 metres. Prospecting by ATMN showed that the lode contained approximately the same proportions of cassiterite and wolframite with the wolframite forming coarse bladed crystals in comparison with small cassiterite grains. HAAG (1943) has suggested that cassiterite occurs with wolframite near the contact with younger granite and that wolfram alone occurs further from the contact. It has not been possible here to study this suggestion but it is a valid concept to apply on a prospectory basis in the

Nigerian Province. Wolframite from the Ropp complex proved on analysis to be ferberite.

FeO	14.7 %
MnO	2.1 %
WO_3	86.0 %
	102.8 %

Analyst: R. A. BATCHELOR

This compares with an analysis of wolframite from El Meki in Aïr presented by RAULAIS (1948).

WO_3	69.1 %
SnO_2	3.0 %
FeO	21.0 %
MnO	2.5 %
SiO_2	0.8 %
CaO	3.4 %
	99.8 %

The wolframite at El Meki occurred in quartz veins in a dome composed essentially of migmatite in contact with cassiterite bearing younger granite.

At Rishi a series of *en enchelon* veins with wolframite and cassiterite occur. The veins may reach three metres in thickness and trend 320°. They occur in porphyritic older granite a short distance from the contact with the Rishi biotite granite but no wolframite was found by the writer in the veins within the contact. HAAG (1943) records large masses of wolframite «the size of a fist» in these basement veins but mining activity has long since removed many of these occurrences and where wolframite is found *in situ* now it is as small bladed crystals.

In the Bukuru area of the Jos Complex, small quantities of wolframite have been recorded by MACLEOD (1956) in a sheer zone in the Jos granite. It has also been recorded by ATMN geologists in quartz veins in the Sabon Gida south biotite granite.

In the Liruei complex, JACOBSON (1947) describes wolframite from quartz veins within the Younger granite at the western end of the Liruei lode as dark brown to black, bladed crystals up to 8 cm. or more in length. The wolframite is often orientated at right angles to the walls of the vein, especially where comb structure is well developed in the quartz. Towards the western end of the lode wolframite is frequently associated with adularia and quartz in drusy cavities.

Although no such crystals were observed by the writer the abundance of tungsten in the lode is unquestionable. The lode is the only vein system within a Younger granite ring complex to show enrichment in tungsten. Values in reddened wall rock adjacent to a greisen vein varied from 1.320 ppm W on one side to 720 ppm on the other side, whilst the vein itself contained 860 ppm W. (Table II). These high tungsten values are probably related to the intrusion of a fine-grained biotite granite at depth within the main Liruei medium-grained biotite granite giving the only example so far of multiple veins.

In general, wolframite mineralization is sporadic and unpredictable, both along the strike and at depth and only those lodes which carry a reasonable amount of cassiterite have proved payable. Despite its widespread occurrence only a few localities have been of economic importance and these have mostly been worked out. Wolframite is only mined as a primary mineral as it does not survive in the alluvials. Misconceptions in past literature about the abundance of wolframite appear to stem from the misidentification of dark brown, metallic looking sphalerite.

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