

HYDROTHERMAL ALTERATIONS ASSOCIATED WITH MOLYBDENITE MINERALIZATION IN THE KIGOM YOUNGER GRANITE COMPLEX, NIGERIA

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ABSTRACT

Petrographic and geochemical evidences show that molybdenite mineralization associated with the anorogenic A-type Kigom younger granite complex is a product of replacement metasomatism. Mineralogical studies indicate that molybdenite began to crystallize at temperature of about 450 °C by replacing microcline and that conversion to microcline was achieved just before the fluid became supersaturated in MoS₂ at which point further reaction of the fluid with the mineral was prevented. The microcline at the ore zone thus has a less ordered structure compared to those from the non-mineralized granite. Studies indicate that sodic metasomatism was the dominant alteration process in the Kigom. Enrichment patterns of trace elements in the ore zone indicate that these represent concentrations of initially incompatible elements present in the magma but deposited when the vapour phase was supersaturated in Mo.

Key Words: Kigom, peralkaline, sodic metasomatism, Nigeria

INTRODUCTION

The Younger Granite complex of Nigeria consists of dozens of high level anorogenic granitic plutons intruded into the Precambrian - Lower Paleozoic basement during the Jurassic (Fig. 1). In these anorogenic ring complexes of Nigeria, a series of hydrothermal alteration processes with related Sn mineralization have been recognized (Kinnaird, 1979; Bowden and Kinnaird, 1984b; Kinnaird, 1985; Abaa, 1991). The Kigom Younger Granite Complex (KYGC) has been identified as one of the later anorogenic intrusions during the Jurassic that have witnessed long duration rock-fluid interaction (Omada *et al.*, in press). A preliminary report on the field studies of the molybdenite mineralization at Kigom has been given (Omada and Martin, 1995). A detailed study of the alteration associated with the molybdenite mineralization has now been undertaken and it is the subject of this paper. The petrography, chemistry of the sodic amphiboles, feldspar mineralogy and whole-rock geochemistry are here used to monitor the extent of alteration at the ore zone.

MATERIALS AND METHODS

Grains of riebeckite and arfvedsonite from ten samples of the Kigom granites were studied and analyzed using the electron microprobe equipped with four automated wavelength-dispersion spectrometers, and an energy - dispersion system (EDS). The composition of the minerals and their recalculated formulas are presented in Table 1 and discussed below.

The molybdenite samples were studied using the SEM for which samples were coated with ultrathin film

of gold by an ion sputter JFCHOO and then exposed under JEOL electron microscope (JSM 35 CF) attached with a four crystal spectrometer at the Regional Research Laboratory, Bhubaneswar, India. The samples were run for Mo, Si, Al, and K (Fig. 2). The composition and degree of Si-Al order of the composite perthite grains in the rock specimens were studied using XRD (powder method) (Table 2).

Whole rock samples of the mineralized and unmineralized riebeckite granite were analyzed chemically (Table 3). Abundances of the major elements, and the elements Nb, Zr, Y, Sr, Rb, Th, Pb, U, Ni, Cr, V, Ba, Cu, Zn, and Co, were determined by the X-ray fluorescence (XRF) technique on fused beads prepared from ignited samples at the Geochemical Laboratory, McGill University, Montreal; matrix correction was by K-compton scatter from Rh X-ray tube. The samples were fused with lithium tetraborate. Matrix correction was done using -correction factors. The detection limit for the major elements was 0.01%, Cr: 15 ppm, V, Ni, Cu, Zn, Co and Ba: 10 ppm, Pb: 4 ppm, Nb, Y, Sr, Rb, Th, and U: 2 ppm. The abundance of FeO was determined using ammonium metavanadate titration; detection limit was 0.01%. The abundances of Mo, W, Be, Li, Sn, As, and Ag were determined using ICP Spectrography at the ACME Laboratories, Vancouver. The abundance of F was determined using an ion-selective electrode and a standard addition technique.

PETROGRAPHY

Ore minerals in the KYGC include molybdenite pyrite, chalcopyrite, sphalerite, galena and genthelvite. The molybdenite is greyish and occurs both as irregular

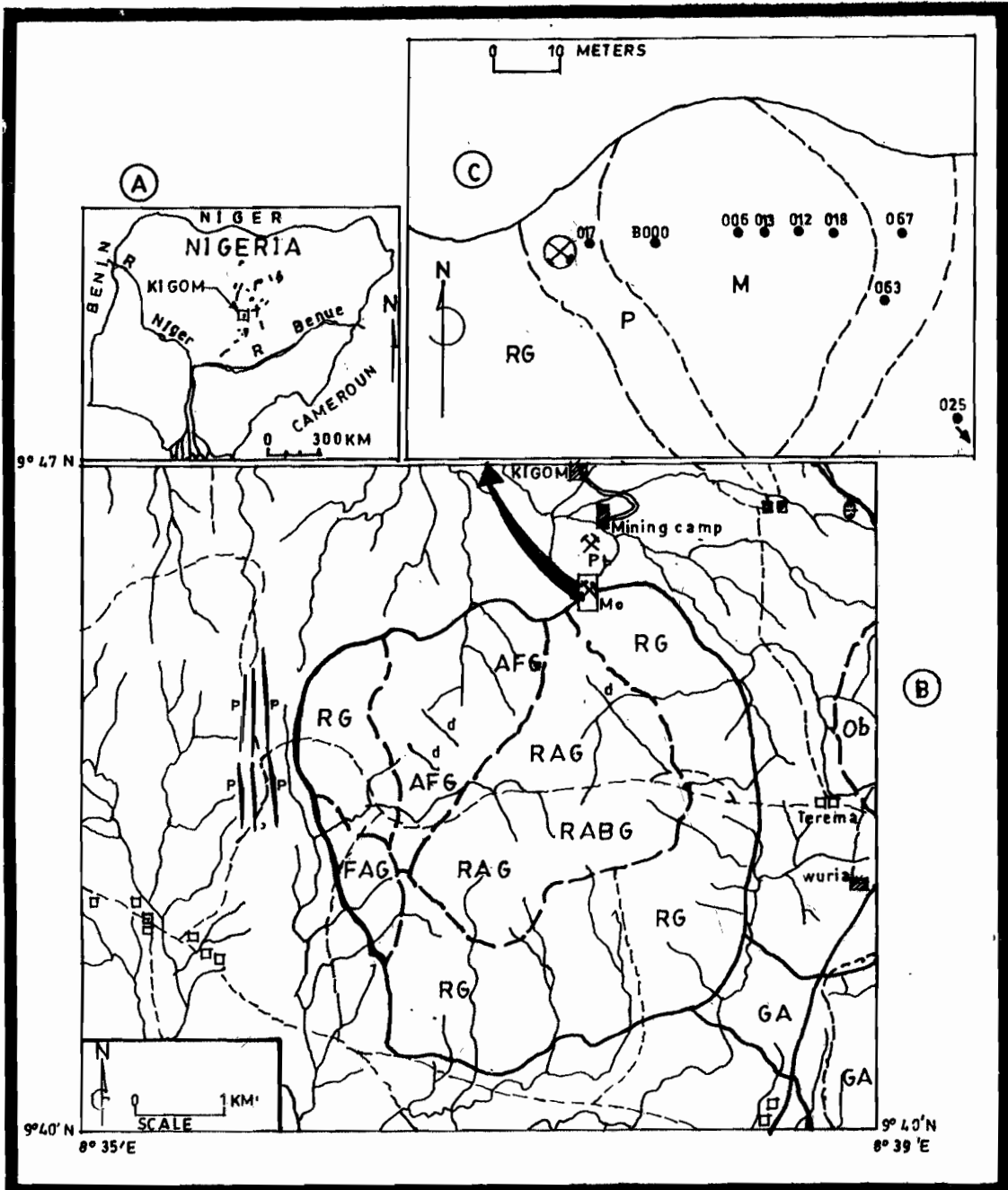


Figure 1. Geological map of the Kigom younger granite complex (KYGC), Nigeria. AFG arfvedsonite granite, RG riebeckite granite, RAG riebeckite aegirine granite, RABG riebeckite aegirine biotite granite, FAG fayalite aegirine granite, D dyke, Ob older basalt, GA Ganawuri granite. Insert (A) map of Nigeria showing the location of the KYGC with respect to the other Younger granites of Nigeria, (C) map of the ore zone at Kigom, P pyrite zone, m molybdenite zone.

flakes and as euhedral trigonal crystals interstitial to perthite and vary in size between 0.5mm and 4cm. Scanning electron microscope images indicate that the poikilitic molybdenite flakes enclose and grow along cleavages of mesoperthite which is being replaced (Fig. 2). Where the replacement is partial, the composition of

the perthite is altered as K and the other elements are removed. K is depleted in portions of the perthite crystals adjacent to and included in molybdenite flakes, the enclosed and adjacent perthite grains show selective contents of Si, Al, and K in which $K < Si < Al$ (Fig. 2) suggesting that the replacement begins with the removal

of K in the rock-fluid metasomatism. Subsequently, Si followed by Al are removed. These elements, now in solution, are responsible for the growth of the latter hydrothermal sheet silicates like biotite and astrophyllite and post-mineralization silica.

FELDSPAR MINERALOGY

On the basis of X-ray diffraction data (powder

method) perthite grains in the mineralized and non-mineralized riebeckite granite contain pure, ordered albite with a composition of $Ab_{98.2}Or_{1.2}$ (Omada, 1992). On the other hand, K-feldspar is microcline in all cases but the degree of order of the microcline defines a range in t_1O from 0.9 to 1.00 (Table 2). The microcline in the mineralized riebeckite granite is not structurally as well ordered ($t_1O = 0.93, 0.96$) as that in the non-mineralized

Table 1 a. The composition and site parameters of arfvedsonite in the Kigom

Oxides	036a	036b	036c	036d	036e	036f	036g	036h	036i	036j	mean
SiO ₂	49.40	49.83	50.85	51.21	49.32	49.74	50.26	50.94	49.48	49.98	50.11
TiO ₂	0.93	0.75	0.77	0.71	0.86	0.69	0.90	1.02	0.85	1.04	0.85
Al ₂ O ₃	0.98	1.18	1.20	1.00	0.97	0.88	1.04	1.20	1.03	0.95	1.04
Fe ₂ O ₃	22.95	21.95	21.75	21.30	22.30	21.37	21.43	21.40	23.64	21.83	22.31
FeO	12.99	14.25	13.30	13.69	12.17	12.61	14.20	13.22	12.13	14.15	13.30
CaO	0.46	0.13	0.11	0.12	0.11	0.30	0.31	0.30	0.27	0.02	0.02
Na ₂ O	7.81	7.84	8.8	7.71	8.11	8.09	7.52	8.03	8.22	8.07	7.96
K ₂ O	1.50	1.39	1.32	1.62	1.27	1.37	1.61	1.52	1.30	1.40	1.43
H ₂ O	0.75	0.93	0.86	0.89	0.62	0.69	0.95	0.88	0.61	0.95	0.81
F	2.48	2.13	2.30	2.23	2.77	2.62	2.08	2.27	2.79	2.09	2.38
O = F	-1.04	-0.90	-0.97	-0.94	-1.17	-1.10	-0.88	-0.96	-1.17	-0.88	-1.00
Total	99.31	99.58	99.57	99.54	99.09	99.16	99.88	99.58	99.08	99.60	99.21
#Si ^{IV}	7.67	7.72	7.81	7.87	7.66	7.71	7.76	7.82	7.68	7.72	7.74
#Al ^{IV}	0.18	0.21	0.19	0.13	0.18	0.16	0.19	0.18	0.19	0.17	0.18
#Fe ⁺³	0.15	0.07	0	0	0.16	0.12	0.05	0	0.13	0.10	0.08
T site	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
#Fe ⁺³	2.53	2.49	2.51	2.46	2.59	2.59	2.44	2.47	2.63	2.44	2.51
#Ti	0.11	0.09	0.09	0.08	0.10	0.08	0.10	0.12	0.10	0.12	0.10
#Fe ⁺²	1.69	1.84	1.71	1.76	1.58	1.63	1.87	1.70	1.57	1.83	1.72
#Ca	0.08	0.02	0.02	0.02	0.10	0.05	0.05	0.01	0.03	0.01	0.04
M1,2,3	4.45	4.50	4.40	4.42	4.42	4.42	4.51	4.38	4.38	4.45	4.43
#Ca	0.08	0.02	0.02	0.02	0.10	0.05	0.05	0.01	0.03	0.01	0.04
#Na	1.92	1.98	1.98	1.98	1.90	1.95	1.95	1.99	1.97	1.99	1.96
M4 site	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
#Ca	-0.08	-0.02	-0.02	-0.02	-0.10	-0.05	-0.05	-0.01	-0.03	-0.01	-0.04
#Na	0.46	0.37	0.42	0.32	0.54	0.48	0.30	0.40	0.51	0.43	0.42
#K	0.30	0.27	0.26	0.32	0.25	0.27	0.32	0.30	0.26	0.28	0.28
A site	0.68	0.62	0.66	0.61	0.70	0.70	0.57	0.69	0.73	0.70	0.67
#O	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
#OH	0.78	0.96	0.88	0.92	0.64	0.71	0.98	0.90	0.63	0.98	0.84
#F	1.22	1.04	1.12	1.08	1.36	1.29	1.02	1.10	1.37	1.02	1.16
Si + Na + K	10.35	10.34	10.48	10.48	10.36	10.42	10.33	10.50	10.41	10.42	10.41
Al ^{IV} + Ca	0.18	0.21	0.22	0.18	0.18	0.16	0.19	0.22	0.19	0.17	0.19

Table 1 b. The composition and site parameters of riebeckite associated with the unmineralized RG in the Kigom

Sample no	008a	008b	008c	008e	008f	Mean
SiO ₂	49.56	50.47	49.44	49.74	49.54	49.75
TiO ₂	0.90	0.65	0.57	0.68	0.70	0.70
Al ₂ O ₃	0.92	0.91	1.01	1.03	0.97	0.97
Fe ₂ O ₃	21.42	21.35	22.63	20.46	22.89	21.75
FeO	15.54	14.85	14.51	16.94	13.70	15.11
CaO	0.30	0.30	0.33	0.41	0.26	0.32
Na ₂ O	7.80	7.81	7.47	7.38	7.93	7.60
K ₂ O	1.40	1.39	1.39	1.42	1.29	1.38
H ₂ O	1.06	0.99	0.86	1.19	0.81	0.98
F	1.83	1.99	2.24	1.55	2.36	1.99
O = F	-0.77	-0.84	-0.95	-0.65	-0.99	0.84
Total	99.76	99.67	99.50	100.15	99.46	99.71
#Si ^{IV}	7.69	7.79	7.68	7.71	7.69	7.71
#Al ^{IV}	0.17	0.16	0.19	0.19	0.18	0.18
#Fe ⁺³	0.14	0.04	0.13	0.10	0.14	0.11
T site	8.00	8.00	8.00	8.00	8.00	8.00
#Fe ⁺³	2.36	2.44	2.51	2.28	2.54	2.42
#Ti	0.11	0.07	0.07	0.08	0.08	0.08
#Fe ⁺²	2.01	1.92	1.89	2.20	1.78	1.96
#Ca	0.05	0.05	0.06	0.07	0.04	0.05
M1,2,3	4.59	4.54	4.57	4.68	4.49	4.57
#Ca	0.05	0.05	0.06	0.07	0.04	0.05
#Na	1.95	1.95	1.94	1.93	1.96	1.95
M4 site	2.00	2.00	2.00	2.00	2.00	2.00
#Ca	-0.05	-0.05	-0.06	-0.07	-0.04	-0.05
#Na	0.34	0.33	0.31	0.29	0.43	0.34
#K	0.28	0.27	0.28	0.28	0.25	0.27
A site	0.56	0.55	0.53	0.50	0.64	0.56
#O	22.00	22.00	22.00	22.00	22.00	22.00
#OH	1.10	1.02	0.89	1.23	0.84	1.02
#F	0.90	0.97	1.10	0.76	1.16	0.98
Si + Na + K	10.25	10.34	10.21	10.21	10.33	10.25
Al ^{IV} + Ca	0.17	0.16	0.19	0.19	0.18	0.18

riebeckite granite ($t_1O = 1.00$) suggesting that the temperature of closure of feldspars in the mineralized granite is higher than that for the non-mineralized granite. Compositionally, the K-feldspar is in most cases more potassic than 96 % Or suggesting a low temperature of

closure. One sample taken near the zone (sample 067), however, contains 88 % Or suggesting that the fluid circulation responsible for the sulphide mineralization at Kigom most probably began at about 450 °C. The destruction or replacement of mesoperthite associated

with the molybdenite mineralization, therefore, began at about this temperature. The K-feldspar was prevented from further reaction as soon as conversion to microcline was achieved following changes in the Eh/pH conditions as the fluid became supersaturated in the sulphide-bearing minerals. This suggests that the deposition of

molybdenite took place early in the replacement metasomatism. Elsewhere, however, the fluid circulation continued and the microcline effectively crystallized to an even greater degree of order, and to a composition even close to the end member at temperature of about 200 °C.

Table 1c. The composition and site parameters of riebeckite associated with the mineralized RG in the Kigom.

Oxides	007a	007b	007e	007f	007g	007i	007j	007k	Mean
SiO ₂	50.50	50.24	50.52	48.67	50.48	49.78	49.36	49.26	49.62
TiO ₂	0.65	0.48	0.55	0.86	0.79	0.54	0.70	0.91	0.65
Al ₂ O ₃	0.92	1.03	0.94	1.10	1.04	1.13	1.17	1.10	1.03
Fe ₂ O ₃	18.30	19.90	19.40	22.54	19.54	21.94	21.56	22.15	21.39
FeO	19.28	17.29	18.08	14.79	17.44	15.04	15.79	14.65	15.73
MnO	0.37	0.39	0.34	0.47	0.37	0.34	0.43	0.34	0.35
CaO	0.30	0.57	0.29	0.42	0.28	0.29	0.35	0.51	0.52
Na ₂ O	7.16	7.20	6.98	7.62	7.02	7.50	7.43	7.79	7.43
K ₂ O	1.31	1.34	1.40	1.42	1.43	1.36	1.31	1.19	1.36
H ₂ O	1.39	1.22	1.24	0.94	1.20	0.96	1.04	0.95	1.03
F	1.16	1.52	1.44	2.07	1.55	2.06	1.87	2.07	1.88
O = F	-0.49	-0.64	-0.61	-0.87	-0.65	-0.87	-0.79	-0.87	-0.79
Total	100.85	100.54	100.57	100.03	100.49	100.07	100.22	100.05	100.02
#Si ^{IV}	7.80	7.77	7.81	7.59	7.79	7.71	7.66	7.64	7.70
#Al ^{IV}	0.17	0.19	0.17	0.20	0.19	0.21	0.21	0.20	0.19
#Fe ⁺³	0.03	0.04	0.02	0.21	0.02	0.08	0.12	0.16	0.12
T site	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
#Fe ⁺³	2.10	2.27	2.24	2.43	2.25	2.48	2.39	2.43	2.38
#Ti	0.08	0.06	0.06	0.10	0.09	0.06	0.08	0.11	0.08
#Fe ⁺²	2.49	2.24	2.34	1.93	2.25	1.95	2.05	1.90	2.04
#Mn	0.05	0.05	0.04	0.06	0.05	0.04	0.06	0.04	0.05
#Ca	0.05	0.09	0.05	0.07	0.05	0.05	0.06	0.09	0.09
M1,2,3	4.77	4.71	4.73	4.60	4.69	4.58	4.64	4.57	4.63
#Ca	0.05	0.09	0.05	0.07	0.05	0.05	0.06	0.09	0.09
#Na	1.95	1.91	1.95	1.93	1.95	1.95	1.94	1.91	1.91
M4 site	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
#Ca	-0.05	-0.09	-0.05	-0.07	-0.05	-0.05	-0.06	-0.09	-0.09
#Na	0.19	0.25	0.14	0.37	0.15	0.30	0.29	0.43	0.32
#K	0.26	0.26	0.28	0.28	0.28	0.27	0.26	0.24	0.27
A site	0.40	0.42	0.37	0.58	0.38	0.52	0.49	0.58	0.50
#O	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
#OH	1.43	1.25	1.28	0.98	1.24	0.99	1.08	0.98	1.07
#F	0.56	0.74	0.70	1.02	0.76	1.01	0.92	1.01	0.92
Si + Na + K	10.21	10.19	10.17	10.17	10.17	10.23	10.16	10.22	10.19
Al ^{IV} + Ca	0.17	0.19	0.17	0.20	0.19	0.21	0.21	0.20	0.19

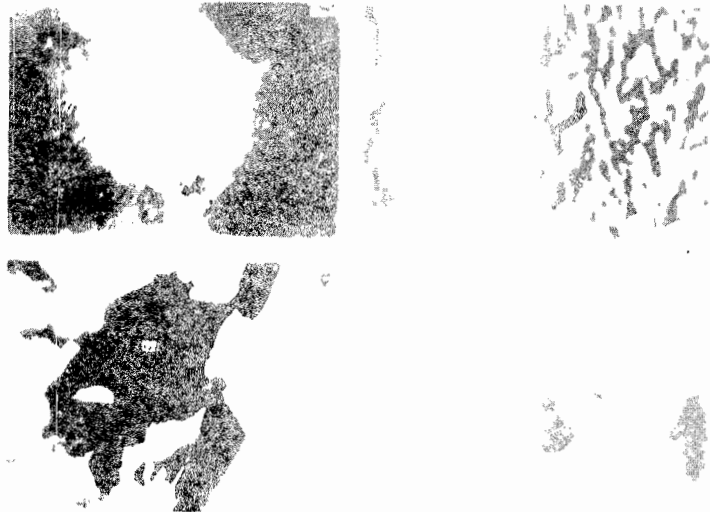


Figure 2a

- A. irregular flakes and bright spots containing earlier crystals of perthite (p). Cross-polars. Bar = 75 microns
- B. Gethelvitite crystal (h) surrounded by molybdenite. Cross-polars. Bar = 75 microns
- C. SEM map of molybdenite
- D. SEM map of molybdenite

MINERAL CHEMISTRY

Compositionally, the amphiboles in the KYGC are generally rich in Si + Na + K, and Fe, but are poor in Ca + ^VAl, reflecting their alkali character (Table 1). The riebeckite crystals contain F values of between 1.55% and 2.55% abundance. It should be noted that the riebeckite grains at the ore zone contain lower values of the K₂O resulting from the loss of K⁺ related to the long duration rock-fluid interaction.

GEOCHEMISTRY

Major Oxides. The ore-bearing RG of the Kigom complex exhibits high contents of SiO₂ (17.5%), and Na₂O+K₂O and low CaO, MnO, and MgO compared to the un-mineralized RG (Table 3). In terms of bulk composition, all the samples have normative Q + Or + Ab > 92% in which Ab > Q > Or, and An is absent. This is characteristic of rocks that have suffered soda metasomatism (Kinnaird, 1985). The samples are peralkaline with agpaite index in the range of 1.06 and 1.11 in which the most intensely mineralized is most strongly alkaline. The contents of normative acmite and hypersthene in the specimen samples from the molybdenite zone are higher than those from the pyrite zone. This suggests that the sodic metasomatism was more intensive as the depositing fluid underwent changes in pH/Eh conditions in the process of crystallization at this zone.

Trace Elements.

The ore zone is rather strikingly enriched in Pb, Cu, Mo, Zn, Zr, Th, U, Y, Nb, and Be (Table 3) compared to the un-mineralized RG. The pattern of enrichment reflects the zoning in mineralization. The pyrite zone typically shows higher values of Zr, Y, U, Th, Nb, and Be, whereas the molybdenite zone is richer in Cu, Zn, Pb, and F; the most strongly alkaline is the richer in chalcophile elements. With respect to background levels, W does not show any preferential enrichment having an abundance of 2-4 ppm. Sr, Co, Li and Ba are depleted in both zones.

Nb is most enriched in the pyrite zone, with 950 ppm; it varies from 289 ppm to 329 ppm in the molybdenite zone. Zr has a similar distribution, varying from 739 to 1393 ppm in the molybdenite zone to 7134 ppm in the pyrite zone. Y ranges from 148-369 ppm in the molybdenite zone to 894 ppm in the pyrite zone. Th is highest in the pyrite zone with 131 ppm, but varies between 22 and 77 ppm in the molybdenite zone. Be, 25 ppm, is very high at the pyrite zone close to the contact with the basement. It has low values of 2.5 ppm in the molybdenite zone.

Mo content varies from 2 ppm in the pyrite zone to 12-85 ppm and 0.3% in the inner molybdenite zone; Mo typically shows such a steep gradient in mineralized plutons (e.g., Bright, 1974). Pb varies from 17 ppm in the pyrite zone to as high as 856 ppm in the molybdenite zone. This is due mainly to the presence of galena. Cu varies from 372 ppm in the pyrite zone to 461 ppm in the molybdenite zone. Zn and U show similar trend to that of Cu. Sn, Bi, and As are enriched in the molybdenite zone.



2b

Scanning Electron image map of molybdenite showing Al, Si, and K. Note that parts of the map showing strong Al and Si images are depleted in K. The white arrow shows that in the metasomatism K is first to be removed.

Table 2. Indicators of composition and degree of Al-Si Order in K-rich and Na-rich feldspars in representative samples from the non-mineralized and mineralized zones of the Kigom Younger granite complex. Composition N_{or} is expressed in mole % Or, and was calculated using the equation of Kroll and Ribbe (1983) relating unit-cell volume to N_{or} for feldspar compositions that belong to the low microcline - low albite series. The degree of Al-Si order, expressed by ξ_{10} was computed using the equations of Blasi (1977). The error in N_{or} and ξ_{10} is believed to be ± 0.015 in most cases. The obliquity Δ of a microcline is equal to $12.5 (d_{131} - d_{131}')$; it should have a value of 1.00 for fully ordered microcline.

S/No	Description	K-rich feldspar				Na-rich feldspar		
		N_{or}	ξ_{10}	Δ	An	N_{or}	ξ_{10}	Δ_{131}
025	RG (unmineralized)	96.0	1.00	1.01	0	1.2	1.01	1.097
067	RG (near the ore zone)	87.8	0.94	0.95	0	1.1	1.01	1.089
B00	RG (pyrite zone)	99.0	0.93	0.91	0	0.7	1.00	1.086
6	RG (molybdenite zone)	99.2	0.96	0.93	0	1.2	1.00	1.083

DISCUSSION

The several hydrothermal alteration processes that have affected the anorogenic ring complexes of Nigeria include sodic metasomatism (the most dominant of the processes), potassic metasomatism, acid metasomatism (responsible for greisenization and related mineralization), chloritization and argillation (Kinnaird; 1979, Bowden and Kinnaird; 1984, Kinnaird et al., 1985, Kinnaird, 1985). In the KYGC, acid metasomatism and associated greisenization are lacking as are chloritization and argillation. Sodic metasomatism is the dominant process in the KYGC. It involves initially, the exchange of K for Na from mesoperthite for the development of the late oikocrystic arfvedsonite and riebeckite, and later, the formation of astrophyllite and aegirine from the amphiboles (Omada, 1992). The long rock-fluid interaction resulted in the modification of textures of the mesoperthite and alkali amphibole reflecting the local removal of Na consumed in the late growth of aegirine and astrophyllite. Silicic metasomatism involves the formation of second generation quartz which is usually poikilitic containing inclusions of riebeckite, perthite and zircon. The included minerals are marginally modified indicating that the metasomatism persisted even after the formation of silica. In the mineralized zones at Kigom, the peralkalinity of the rocks is even greater than in the non-mineralized parts of the complex. The control here is the restriction of the fluid to the contact regions resulting in long duration rock-fluid interaction. Field and petrographic evidence of the mineralization at Kigom show no relationship of the depositing fluid with greisenization; a phenomenon that has been linked to molybdenite mineralization, for example, at Henderson (e.g. Mackenzie, 1970) and thought to be a distinct, late-stage event related to a deep late intrusion termed "Henderson granite". The lack of greisenization in the Kigom distinguishes the mineralization at Kigom from the molybdenite mineralization at Henderson and from many of the vein-type tin-zinc mineralization in some of the Nigerian Younger Granite complexes, for example, at the Ririwai complex (Bowden, 1982) where greisenization is also a common phenomenon.

Bowden (1982) classified the sodic amphiboles in the Younger Granite complex of Nigeria as

"riebeckitic arfvedsonites". The amphiboles of the KYGC, however, show three compositional groupings on the Si + Na + K content: the arfvedsonite crystals of the AFG have the highest value of 10.41, riebeckite crystals from the RG and RAG (Fig. 1) and the ore zone have lower values of 10.25 and 10.19 respectively (Table 1). This trend of the amphiboles indicates that in the KYGC, the amphiboles were primarily arfvedsonitic and that the arfvedsonite grains underwent oxidation on crystallization; the more intensely metasomatized crystals being found among the grains at the ore zone.

That the feldspars in the mineralized zone contain mesoperthite in which the microcline is structurally not as well ordered as those associated with the non-mineralized RG indicates that the deposition of the ore mineral took place early during the alkali metasomatism. The feldspar composition also shows that fluid circulation probably began at the late magmatic stage (T of about 450 °C) and that the deposition of the Mo also is late magmatic.

Table 3. Bulk composition of representative samples of the non-mineralized and mineralized riebeckite granite (RG) of the Kigom complex. RG025 unmineralized riebeckite granite, RG017 pyrite zone, RG012, RG018 and RG013 are samples from the molybdenite zone. See figure 1 for location of samples.

Oxides wt%	RG 025	RG 017	RG 012	RG 018	RG 013
SiO ₂	76.45	76.59	76.15	75.65	75.71
TiO ₂	0.18	0.15	0.14	0.12	0.17
Al ₂ O ₃	10.88	11.33	11.02	10.96	10.94
Fe ₂ O ₃	0.51	0.99	0.83	1.42	0.90
FeO	2.00	2.16	2.41	2.01	2.43
CaO	0.06	0.11	0.10	0.13	0.11
Na ₂ O	5.03	4.59	4.60	4.57	4.55
K ₂ O	2.53	4.08	3.76	4.26	4.29
P ₂ O ₅	0.01	0.01	0.10	0.01	0.02
L.O.I	0.24	0.24	0.22	0.32	0.29
Total	97.89	99.25	99.33	99.44	99.33
norm	(moles%)				
Ap	0.02	0.02	0.21	nd	0.04
Il	0.26	0.21	0.20	0.17	0.24
Mt	0.33	nd	nd	nd	nd
Or	15.44	24.59	22.87	25.67	25.84
Ab	45.90	38.49	38.71	35.35	35.04
Di	0.19	0.39	nd	0.52	0.34
Hy	2.86	3.04	3.64	2.76	3.46
Ac	0.60	2.82	2.36	4.04	2.56
Q	34.61	30.44	32.16	31.05	31.45
Trace	elements (ppm)				
Nb	950	329	289	212	318
Zr	7134	589	971	714	739
Y	894	174	192	179	148
Sr	43	3	2	3	3
Rb	400	296	274	280	323
Pb	18	102	111	856	98
Th	131	55	59	43	77
U	35	10	9	nd	6
Cu	372	174	287	528	65
Zn	498	874	528	856	411
Mo	2	5	12	85	2750
W	3	2	4	2	2
Li	22	95	121	111	93
F	1400	1690	1430	1720	1860
Sn	30	13	14	10	17
Ba	32	1	2	1	5
ratios					
Na + K/Al	1.01	1.06	1.06	1.11	1.11
Rb/Sr	145	9	137	93	108
Rb/Ba	12	296	137	280	65
Zr/Y	8	4	5	4	5

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