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Precambrian Granitoids from Two areas in Western Tanzania: the Archean Bukoli Pluton and the Proterozoic Kate Batholith

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Abstract: Microscopic observation, magnetic susceptibility studies, chemical analyses for major elements and sulfur and tin have been done on selected samples from two Precambrian granitic areas in Tanzania: the Bukoli plutons, south of Lake Victoria, which are Archean and intrusive to the Nyanzian Greenstone Belt, and the Kate batholith, in the southwest, which is Proterozoic and late-orogenic to the Ubendian System. Some of the Kate samples were also examined for their sulfur isotopic composition.

Both granitoids have strongly oxidized, magnetite-series character. The Archean granitoids have homogeneous composition (72–75% SiO_2) and are characterized by high Na_2O/K_2O ratios, while the Proterozoic ones are heterogeneous in composition (58–75% SiO_2) and severely sheared in texture, and are more potassic than the Archean granitoids. Thus they are of independent magma types. The Proterozoic granitoids are sheared soon after the emplacement and the original magnetite-hornblende-biotite-feldspars assemblage is partially or completely modified to hematite-ilmenite-sphene-epidote-clinozoisite-biotite-muscovite assemblage whilst loosing the magnetic susceptibility.

The Archean granitoids are sodic and impoverished in sulfur and tin, and accompany gold-quartz veins in the surrounding Nyanzian greenstones. The most sodic one having epidote-chlorite alteration assemblage appears to be most suitable for the gold mineralization. The Proterozoic granitoids have general characteristics of those related to the base metal sulfide ore, though no mineralization has been known to date. There is little hope of finding tin granite in the studied area, because the granitoids are of magnetite-series and their tin content is extremely low (below 2 ppm).

Introduction

Granitic rocks occupy very large areas of Tanzania, ca. 25%, and all are considered to have been formed during the Precambrian time. The granitic rocks are subdivided into syn-orogenic, late-orogenic and post-orogenic types in the Geological Map of Tanganyika by Quennell (1960). The late- and post-orogenic granitoids are considered to be related to mineralization such as those in the tin-tungsten belt of the Karagwe-Ankolean System, basemetal-gold belt of Mpanda Mineral Field in the Ubendian System and the Archean Goldfield around Lake Victoria (Harris, 1961).

The Precambrian granitoids of Tanzania have been studied under field mapping projects and only brief petrographic works have been made in the laboratory. Here two areas are considered for more detailed studies: Bukoli granitoids within Archean Goldfield and Kate granitoids of Proterozoic Ubendian belt which

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may be tin and basemetal-gold mineralized. These areas were previously mapped by Nanyaro *et al.* (1978) and Semyanov *et al.* (1971), respectively, within the framework of the regional geological mapping program of the Geological Survey of Tanzania.

Eight granitoids and 3 greenstones were selected from the Bukoli area; 12 samples were chosen from one transect across the Kate granitic complex. These rocks were sliced and powdered at the Geological Survey of Japan for making thin and polish sections, measurement of magnetic susceptibility and chemical analyses of major and some minor elements. The results are reported in this paper in order to establish petrographic characteristics and petrogenetic history of the Tanzanian granitoids and also to asses their potentiality with regard to mineralization.

General Geology

Bukoli Area

The Bukoli area is situated in the north-northwestern part of Tanzania and south of Lake Victoria (Fig. 1). The Bukoli granitoids occur in the Nyanzian System, which, together with the Kavirondian and Dodoman System, make up the Tanzania Archean Craton (or Tanzania Shield). Isotopic age of rocks of the Craton is at least 2,500 Ma (Dodson *et al.*, 1973; Coomer and Robertson, 1974; Priem *et al.*, 1979).

The Nyanzian System is built up of low grade meta-volcanics of basaltic to dacitic composition known as greenstones, banded iron formation, phyllite and schists. Characteristics of the Nyanzian System are similar to those found in Greenstone Belt of other Archean Cratons of the world; *e.g.*, the Yellowknife district, Canada and the Barberton Belt of Swaziland-South Africa. Thus the System is often referred to as the Nyanzian Greenstone Belt.

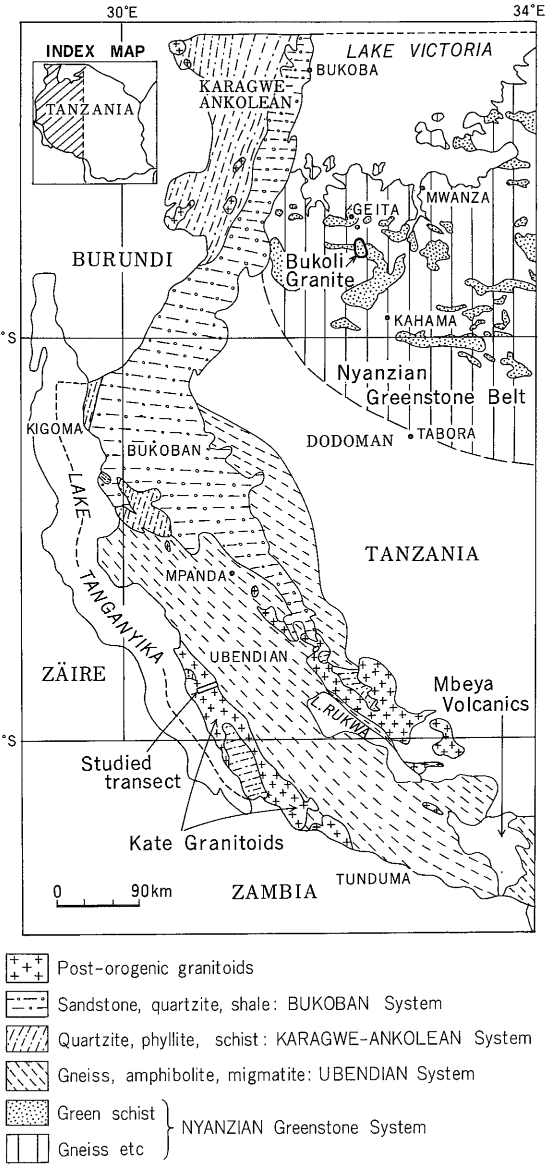

Fig. 1 Location of the Bukoli and Kate granitoids and main Precambrian tectonic belts of western Tanzania. Modified from Quennell (1960).

The Bukoli granitoids occur as scattered small plutons. The main pluton has dimensions of 11 (ENE) by 17 (NNW) km, and is intrusive into east-west trending greenstones and gneissic granitoids. The Bukoli granitoids have not been dated, however, from field and laboratory evidence and age data for similar granitoids elsewhere in the Craton (Yanagi and Suwa, 1981), the age is supposed to be 2,500 Ma or older; thus Archean.

The main, Bukoli pluton shows intrusive characteristics on its margin where xenoliths of the greenstones are abundantly contained

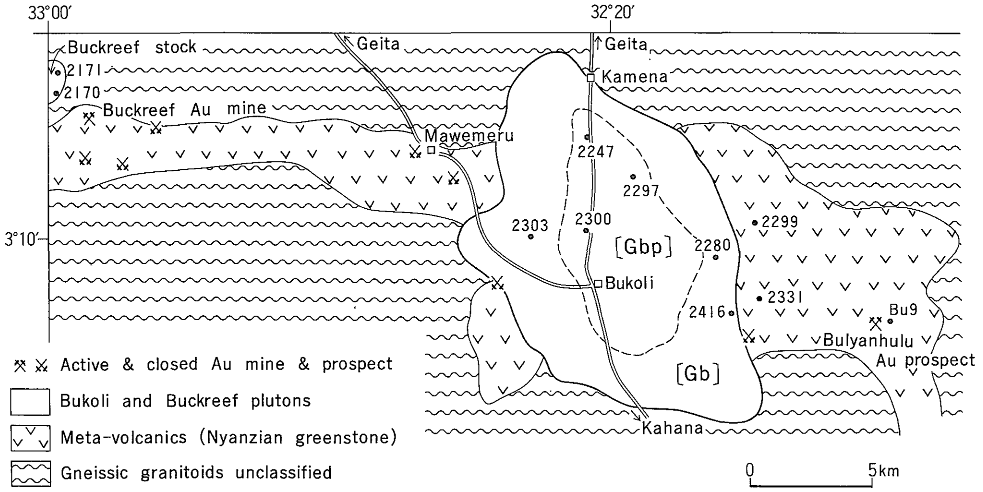

Fig. 2 Simplified geologic map of the Bukoli area with location of the studied samples. The Buckreef stock is located at the northwestern corner. [Gb] and [Gbp] in the Bukoli granite imply biotite granite (margin) and porphyritic biotite granite (center).

and where the greenstones have a hornblende-epidote assemblage instead of chlorite-clinozoisite one at distance from the contact. The pluton is composed of coarse-grained, massive biotite granite[1]. In the field, the granite is clearly divisible into two zones; inner porphyritic zone with K-feldspar phenocryst, and outer equigranular zone with coarse grains of quartz, microcline and oligoclase (Nanyaro *et al.*, 1978).

A much smaller but similar massive granitoid occurs 20 km west of the Bukoli granite close to the Buckreef gold mine, which is tentatively called the Buckreef stock (Fig. 2). It is leucocratic biotite granodiorite. Characteristics of these granitic bodies are numerous gold quartz veins clustered around them. Intensity of the mineralization appears stronger around the Buckreef stock where a gold mine is under operation.

Kate Area

This is situated in the southwestern part of Tanzania and northeastern Zambia (Fig. 1). Granitic rocks on the Tanzanian side occur as a large linear body of over 200 km in length and 70 km in width. It has a general northwest-southeast trend almost concordant with that of the intruded metamorphic rocks. The body is a composite batholith intrusive into rocks of the Ubendian System, which is also referred as the Rusizian Belt in northeastern Zaire and Burundi.

The Ubendian System is composed of biotite gneisses, amphibolites, mica schists, quartzites, migmatites and granitic gneisses (Quennell *et al.*, 1956). The orogenic event leading to the main episode of deformation and metamorphism of the Ubendian rocks is dated to be ca. 2,000 Ma (Cahen and Snelling, 1966; Dodson *et al.*, 1975; Priem *et al.*, 1979). This event is recorded in many places of Africa and is generally referred as the Eburnian Orogenic Cycle.

The Ubendian rocks are overlain unconformably by sandstones and shales assigned to the Bukoban System. The Bukoban rocks have age data between 800 and 1,000 Ma (Cahen and Snelling, 1966, 1974; Piper, 1972).

The age of the Kate batholith is not known for certain in Tanzania since only one K-Ar mineral age of 1725±70 Ma is available (Snelling *et al.*, 1972). The age agrees well with field observations where the Kate batholith is intrusive into rocks of the Ubendian

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[1] Terminology of granitic rocks used in this paper are the one recommended by IUGS Subcommissin on the Systematics of Igneous Rocks (1973).

System and post-dates the sedimentation of the Bukoban rocks. In addition, Rb-Sr whole rock age of 1833±18 Ma for rock suite similar to the Kate batholith on the Zambian side has been recently determined by Brewer *et al.* (1979). Thus the age data and field observations suffice to assign the Kate batholith to the Late-Ubendian Orogenic granitoids.

The Kate granitoids are heterogeneous containing various rock types but mostly biotite granite. They are often foliated and sheared. Crushed augens of pink-purple K-feldspars in finer grained matrix are characteristic of the granitoids. Comagmatic volcanic and subvolcanic equivalents (*e.g.* U138) are present as the roof-pendant or as intruded wall rocks. These rocks are also sheared. Semyanov *et al.* (1971) recognized the following rock types within the Kate granitic complex:

(1) Granite porphyry and granosyenite porphyry
(2) Biotite granite
(3) Coarse-grained porphyritic biotite granite and granodiorite (Kate type)
(4) Porphyroblastic granodiorite and plagiogranite
(5) Kate subvolcanic formation (granosyenite porphyry and granite porphyry)
(6) Kate volcanites (rhyolite and dacite with respective tuffs)

The mode of emplacement of the Kate granitoids appears to be tectonically controlled whereby the intrusion pierced the supracrustal rocks along tectonically weak, northwest-southeast lineament. The weak zones were re-activated after the granitoid emplacement causing strongly foliated, augen-gneissic texture and preferred mineral orientation.

The Kate granitic body lies within the Ubendian gold-basemetal province and it is speculated that the tin granite of the Karagwe-Ankolean may occur in this area; however no mineralization has been found to date associated with the batholith.

Microscopic Observation

Bukoli Granitoids

These granitoids are non-foliated, holocrystalline and granular in texture. In the central part of the main Bukoli pulton, phenocrysts of K-feldspar are abundant imparting on the granite a porphyritic texture. The pluton is granite in composition and is normatively plotted near granite-granodiorite boundary (Fig. 3). The Buckreef stock is similar in texture to the main phase of the Bukoli pluton, but differs in plagioclase/K-feldspar ratio in which the Buckreef falls in granodiorite (Fig. 3).

Main constituents of the granitoids are quartz, K-feldspar, plagioclase and biotite. Quartz is abundant in all samples and occurs as large, anhedral crystals. In the northeastern part of the Bukoli pluton, crushed quartz is noted, due probably to local shearing.

K-feldspars are microcline and microcline perthite, and are often phenocrystic (up to 15 mm long) carrying inclusions of earlier formed plagioclase and biotite. In the Buckreef stock, K-feldspars are fewer and occur often as subhedral grains with quartz.

Plagioclase is euhedral and has a composition of albite-oligoclase. Average normative ab/ab+an ratios of both plutons are 0.84. Plagioclase is rarely zoned in the Bukoli granite, whereas the mineral is commonly zoned in the Buckreef body. In addition, myrmekitic texture is seen around the plagio-

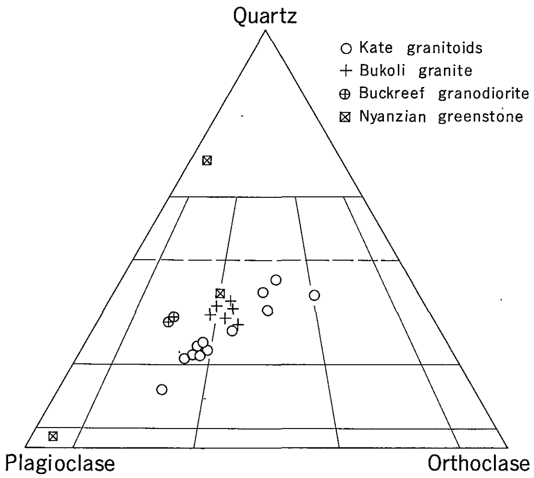


Fig. 3 Normative salic ratio of the studied granitic and volcanic rocks (wt%).

clase of the Buckreef stock. Plagioclase contains small grains of epidote-group minerals and flakes of sericite.

Biotite is ubiquitous mafic sillicate and occurs all over the granitoids, as large euhedral flakes or fine aggregates of recrystallized forms. Its color is Z≒Y=brownish green but more greenish on the recrystallized one. The mineral has been partly altered to chlorite, epidote and opaque oxides, but chlorite is more distinct in the Buckreef stock than the Bukoli pluton. Wedge-shaped, euhedral sphene is abundant in the Buckreef body, while it occurs mostly as anhedral grains of alteration products in the Bukoli pluton.

Opaque minerals are rare and if present, magnetite is common. Ilmenite occurs in very small amount. Sulfides are nearly absent but is pyrite if present. Three greenstones collected from the Bulyanhulu gold prospect area (BU9) and areas close to the Bukoli granite pluton (NA2299, 2331, Fig. 2), are also studied. A volcanic texture is obviously seen on the sample BU9 whereby fragmental phenocrysts of mostly plagioclase and quartz occur in foliated groundmass. The groundmass is composed of fine crystals of sericite, carbonates and chlorite together with some salic minerals. This rock may be originally dacitic tuff for the fragmental phenocrysts and SiO_2 content of 66%. Some of the quartz phenocrysts are cracked and filled with the alteration products, so that the foliation is partly due to local shearing related to the gold occurrence in the deposit.

The greenstones occurring close to the Bukoli granite are strongly altered and recrystallized, probably due to the effect of the granite intrusion. The sample NA2299 is completely covered by a mat of actinolite and less amount of epidote-group minerals, and no original texture is observed. The rock is considered originally basaltic rock for its low silica content (46% SiO_2).

The sample NA2331 (65% SiO_2), on the other hand, is completely recrystallized rock. Euhedral bluish green amphiboles associated with zoisite occur together with quartz. No feldspars are observed which is shown in very low alkali and alumina contents (Table 1). The rock may be originally basaltic tuff intermingled with some siliceous rock. The amphiboles and quartz show banding. Thus it is speculated that the rock is also sheared and completely recrystallized during intrusion of the Bukoli granite. The mineral assemblage indicates that the Nyanzian greenstones close to the granite has been metamorphosed up to epidote-amphibolite facies by this intrusion.

Kate Granitoids

The Kate granitoids examined consist of coarsely foliated granitoids with protoclastic texture and rarely holocrystalline massive with hypidiomorphic texture. Phenocrysts of K-feldspar occur in some parts giving the rocks porphyritic or augen-gneissic texture. Stress effect is obvious under the microscope; the foliation is considered to be due to tectonic shearing. The granitoids are mostly granite but range in composition from granodiorite to syenogranite, and are plotted mostly in the granite-granodiorite field of the normative quartz-feldspars diagram (Fig. 3).

Quartz, K-feldspars, plagioclase and biotite are the main constituents of these granitoids. Hornblende is rare and muscovite is abundant but of mostly secondary origin. Characteristics of the Kate granitoids are abundant occurrence of epidote-group minerals and sphene, which will be described later. Opaque minerals, if present, are largely magnetite; ilmenite is present in very small amount. Some sulfides occur, commonly as pyrite.

The Kate granitoids show compositional variation across the batholith. In the western part, they are biotite granodiorite-granite and strongly sheared. The west-central part is least sheared and most mafic being biotite granodiorite or quartz monzodiorite; small amount of hornblende is present in the quartz monzodiorite (*e.g.*, U143). In the eastern part, the granitoids are strongly sheared and are leucocratic biotite granite. Two-mica granite is present (U151), in which trace amount of garnet occurs. But the exposure is very much limited to sheet-like bodies. The east-west variation is shown on selected normative constituents in Fig. 4.

Table 1 Chemical composition of granitoids

Sample no.	Buckreef stock NA2171j	 NA2170j	Bukoli NA2303j	 NA2247j	 NA2300j
SiO_2(%)	72.64	72.83	74.57	73.31	72.12
TiO_2	.196	.187	.174	.253	.216
Al_2O_3	14.67	14.43	13.56	13.50	14.23
Fe_2O_3	.94	1.08	.94	1.02	1.13
FeO	.50	.43	.47	.93	.72
MnO	.029	.029	.048	.053	.054
MgO	.36	.40	.26	.52	.44
CaO	1.75	1.84	.96	1.68	1.63
Na_2O	5.25	5.06	4.07	3.91	3.93
K_2O	2.42	2.48	4.34	3.69	4.17
P_2O_5	.053	.070	.046	.063	.063
H_2O+	.87	.80	.45	.59	.60
Total	99.68	99.63	99.89	99.52	99.31
KT-3 (CGS)	110	140	70	50	30
TH-1 (SIU)	620	700	275	270	170
S(ppm)	0	0	0	10	0
Sn(ppm)	.5	.4	.9	1.4	1.5
Q (%)	28.67	29.59	31.97	32.03	29.28
C	.35	.26	.53	.18	.44
or	14.29	14.66	25.65	21.79	24.67
ab	44.46	42.81	34.45	33.06	33.22
an	8.36	8.64	4.44	7.93	7.68
wo-di	0.00	0.00	0.00	0.00	0.00
en-di	0.00	0.00	0.00	0.00	0.00
fs-di	0.00	0.00	0.00	0.00	0.00
en-hy	.89	.99	.64	1.29	1.09
fs-hy	0.00	0.00	0.00	.54	.13
mt	1.14	.94	1.17	1.48	1.64
hm	.16	.43	.14	0.00	0.00
il	.37	.35	.33	.48	.41
ap	.12	.16	.11	.15	.15
Others	.87	.80	.45	.59	.60
Total	99.68	99.63	99.89	99.52	99.31
Q+or+ab(%)	87.43	87.06	92.07	86.89	87.17

Localities are shown in Fig. 2. Buckreef stock: NA2171, 2170, Biotite granodiorite (moderate alteration). Bukoli plution: NA2303, (strong alter.); NA2280, 2146, Biotite granite (weak alter.). Nyanzian greenstone: NA2299, Epidote-actinolite basalt (strong elements by H. HATTORI and H. HIRANO; S by E. MATSUMOTO; Sn by S. TERASHIMA. KT-3 (CGS) and TH-1 (SIU) are Data Analysis Program, M. YOSHII and T. SATO, in prep.). n.d., not determined.

Quartz is anhedral showing more or less strain shadows and wavy extinction. In strongly sheared granitoids, fine aggregates of secondary quartz with sutured outline are observed. K-feldspars are microcline, microcline-perthite and less common perthite alone. In the eastern part, microcline occurs solely. The minerals sometimes occur as porphyroblastic phenocryst, giving rise to an augen-gneiss texture. Plagioclase is euhedral or rounded having composition and meta-volcanics of the Bukoli area

pluton			Nyanzian greenstone		
NA2297j	NA2280j	NA2146j	NA2299j	NA2331j	BU-9j
72.04	75.33	72.84	46.68	65.30	65.50
.240	.167	.244	1.150	.509	.392
14.39	13.17	14.16	14.39	5.81	15.78
.97	.75	1.18	2.42	3.74	1.59
.97	.50	.72	10.02	10.67	2.87
.045	.045	.056	.203	.182	.068
.63	.22	.39	5.22	3.17	1.81
1.56	1.04	1.35	14.65	6.84	1.59
3.77	3.98	4.43	1.20	.33	2.99
4.71	4.14	3.61	.34	.33	3.03
.069	.042	.064	.075	.050	.085
.75	.43	.72	1.60	2.06	3.46
100.14	99.81	99.76	97.95	99.00	99.18
<10	100	90	20	20	10
30	300	700	n.d.	n.d.	n.d.
0	0	0	n.d.	n.d.	n.d.
1.2	1.7	1.2	.7	.9	.8
27.68	33.83	29.94	1.15	39.93	29.05
.42	.36	.66	0.00	0.00	4.89
27.86	24.48	21.36	2.04	1.97	17.91
31.91	33.70	37.47	10.16	2.82	25.32
7.28	4.86	6.28	32.85	13.37	7.35
0.00	0.00	0.00	16.43	8.44	0.00
0.00	0.00	0.00	7.59	2.87	0.00
0.00	0.00	0.00	8.69	5.81	0.00
1.56	.55	.96	5.40	5.03	4.52
.67	.11	.05	6.18	10.18	3.43
1.40	1.09	1.70	3.51	5.43	2.30
0.00	0.00	0.00	0.00	0.00	0.00
.46	.32	.46	2.18	.97	.74
.16	.10	.15	.17	.12	.20
.75	.43	.72	1.60	2.06	3.46
100.14	99.81	99.76	97.95	99.00	99.18
87.45	92.01	88.76	13.34	44.71	72.29

2247, Biotite granite (weak alter.); NA2300, Epidote-bearing biotite granite (mod. alter.); NA2297, Epidote-biotite granite alter.); NA2331, Epidote-amphibole-quartz rock (strong alter.); BU9, Altered dacitic tuff. Analysts for Tables 1 and 2: Major magnetic susceptibility in 10^{-6} and 10^{-5} orders, respectively (see text). CIPW norms are calculated by GEOCAPS (Geochemical

of albite-oligoclase and andesine. This mineral is generally unzoned. Plagioclase has undergone partial or complete replacement by sericite, epidote and clinozoisite.

Main ferromagnesian minerals are biotite, mucovite-sericite, epidote-group minerals, sphene and magnetite, in order of abundance. Biotite consists of euhedral-subhedral, Z$\doteqdot$Y= brownish green crystals and more greenish fine flakes which follow the foliation of the

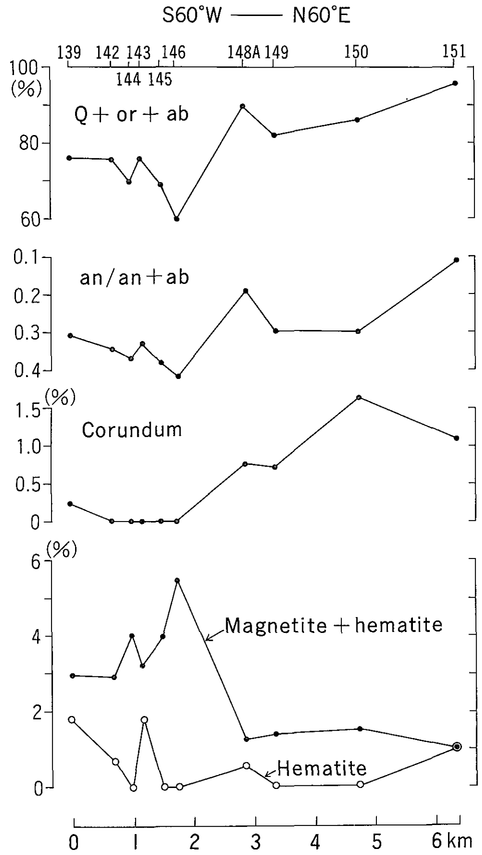


Fig. 4 East-west variation of selected normative components along the studied transect across the Kate batholith. Note that the eastern part is more felsic than the western part.

granitoids. Muscovite-sericite occurs in almost all the samples. Small flakes replacing feldspar, which is generally plagioclase, are secondary in origin and are called sericite in this paper. Some other euhedral-subhedral flakes occur with biotite as bands or alone along the grain boundaries of salic minerals. This may be also secondary in most cases (*e.g.*, U148A, 149, 150). However, muscovite in the leucogranite (U151) and aplitic granite which could be irregular form of dike (U148B) is large euhedral crystal. Together with the presence of garnet in these rocks, the leucogranite may be considered to have had originally a muscovite-biotite assemblage.

Epidote and clinozoisite occur in abundance as a mat of fine aggregates replacing plagioclase or subhedral-granular aggregates replacing plagioclase, or subhedral-granular aggregates associated with mafic minerals. The epidote-group minerals in leucocratic biotite granite of the eastern part occur as fully recrystallized, separate, euhedral to subhedral grains in the foliae with other major rock-forming minerals. Sphene is common accessory mineral occurring as large euhedral crystals (up to 1 mm) in most cases and rarely as fine granular crystals. Hemo-ilmenite may be contained in the euhedral sphene.

Most of the mafic minerals of the Kate granitoids have been modified to some extent from their original assemblages. Recrystallized minerals are more host mineral-dependent in the western part but occur as euhedral independent crystals in the eastern part (U148–151). K-feldspars in the eastern part are all microcline. Thus, the recrystallization condition of the post-magmatic history differs within the Kate batholith.

Magnetic Susceptibility and Fe-Ti Oxide Minerals

From the epidote-sphene assemblage and the color of biotite which is Mg-rich variety, it is clear that the studied granitoids belong to magnetite series of ISHIHARA (1977). Magnetic susceptibility was measured by Kappameter KT-3 (ISHIHARA, 1979a) and TH-1 device. Due to the heterogeneous nature of the rocks it was found necessary to make at least three magnetic susceptibility measurements on the hand specimen at different places and the average values are listed in Tables 1 and 2. Good agreement between Kappameter KT-3 and TH-1 measurements was obtained. The measurements indicate that most of the granitoids have much lower magnetic susceptibility than that of typical magnetite-series granitiods in Japan.

Among the Archean granitoids, the Buckreef granodiorite is most magnetic having the magnetic susceptibility of $110–140\times10^{-6}$ emu/g, which exceeds the lower limit (100×10^{-6} emu/g) for the magnetite series but one-quarter of the value of the typical magnetite-series rock of similar silica content (Ishihara, 1979b). The Bukoli granite has a lower range between 5 and 100×10^{-6} emu/g. Magnetic susceptibility of common granitoids is almost entirely dependent upon content of magnetite.

Iron-titanium oxides of the Buckreef granodiorite are mostly scattered, polygonal magnetite. The magnetite has been hematitized at its margin, which is resulted from oxidation during the deuteric stage. Ilmenite is present as minute, subhedral crystals (primary) in biotite and as irregular lamellae (secondary) filling cleavage and cracks of altered biotite. The Bukoli granite contains also small amount of scattered magnetite grains. Magnetite is mostly polygonal crystals that contain hematite lamella along the cleavages on some crystals, this may be product of subsolidus reaction. Ilmenite is rare but some stubby euhedral crystals are seen in biotite. Secondary ilmenite occurring in biotite is fairly common.

Magnetic susceptibility of the Kate granitoids varies greatly from 10 to 720×10^{-6} emu/g. It varies greatly even on hand specimen of foliated rocks. Thus the heterogeneity is due to the regional shearing and concomitant recrystallization of the granitoids.

Magnetite of the Kate granitoids is polygonal and usually occurs with biotite. Hematite lamellae are common and hematite in irregular form replaces magnetite along the edge or cracks. Small crystals in the leucocratic granite of the eastern part are almost completely hematitized. Large crystals of magnetite-rich rock (*e.g.*, U144) contain polygonal to bleb-like pyrite. Ilmenite is present but does not occur associated with magnetite, which is also the case in the Bukoli granitoids. Ilmenite is generally seen in sphene as small elongated crystals. The ilmenite includes hematite lamellae up to ca. 30% in volume.

Iron-titanium oxides of magnetite-free granitoids are only few grains of ilmenite. They occur in sphene generally in irregular form. The ilmenite contains up to ca. 20% in volume of irregularly shaped hematite. In the leucocratic granite of the eastern zone (*e.g.*, U151), hematite with ilmenite lamellae (up to ca. 20%) is abundant. These minerals occur in rectangular shape generally, but some others have granular-polygonal habit indicating that this may have been originally magnetite. Generally speaking, the Kate granitoids contain specks of hematite and zoned limonite occurring along mineral boundary and cracks, which are most likely the latest oxidation products.

As is obvious from the description above, the Kate granitoids were oxidized after the original formation. This is shown by the very high Fe_2O_3/FeO ratios (see values of Fe_2O_3 and FeO in Tables 1, 2). The ratio exceeds the general lowest limit (0.5) of magnetite-series granitoids (Ishihara, 1981) in both the Kate and Bukoli granitoids (Fig. 5). The Nyanzian greenstones belong to reduced type. The ferric/ferrous ratios of the Kate granitoids vary from 1 to 3.6 in most rocks but the ratio goes up to 7.3 in the well fractionated phase (U148b, 151), which is the general trend of magnetite-series granitoids (Czamanske *et al.*, 1981).

In Fig. 5, main phase rocks of both the Kate and Bukoli granitoids vary largerly in the magnetic susceptibility. This is contrast to the Nyanzian greenstones which are low in both

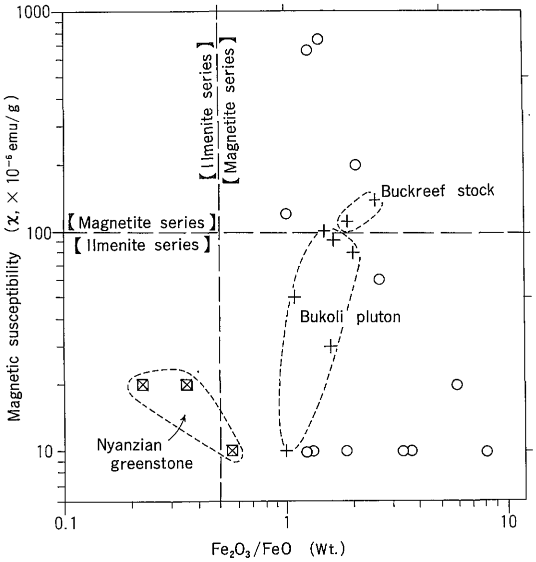


Fig. 5 Magnetic susceptibility vs. ferric/ferrous ratio of the studied granitic and volcanic rocks.

Table 2 Chemical composition

Sample no.	U139j	U138j	U142j	U144j	U143j
SiO_2(%)	65.87	65.55	66.60	63.64	66.16
TiO_2	.475	.590	.493	.698	.565
Al_2O_3	16.43	16.29	15.90	16.08	15.78
Fe_2O_3	2.58	2.23	2.21	2.77	2.78
FeO	.72	1.19	1.08	2.01	.86
MnO	.069	.083	.068	.092	.074
MgO	.96	.97	.94	1.62	1.07
CaO	3.20	3.46	3.49	4.25	3.39
Na_2O	3.96	3.57	3.62	3.54	3.78
K_2O	3.89	3.98	3.75	3.46	3.63
P_2O_5	.148	.155	.153	.231	.163
H_2O+	1.18	1.19	.97	1.01	1.17
Total	99.50	99.26	99.28	99.41	99.41
KT-3(CGS)	10	10	200	720	10
S(ppm)	10	0	60	20	40
Sn(ppm)	1.8	2.0	1.7	1.8	1.9
Q (%)	20.05	21.15	22.77	19.10	22.00
C	.23	.20	0.00	0.00	0.00
or	23.01	23.53	22.18	20.47	21.44
ab	33.53	30.18	30.67	29.99	31.95
an	14.92	16.14	16.04	17.72	15.41
wo-di	0.00	0.00	.10	.77	.14
en-di	0.00	0.00	.09	.61	.12
fs-di	0.00	0.00	0.00	.06	0.00
en-hy	2.39	2.41	2.25	3.43	2.53
fs-hy	0.00	0.00	0.00	.35	0.00
mt	1.17	2.40	2.27	4.02	1.37
hm	1.77	.58	.64	0.00	1.83
il	.90	1.12	.94	1.33	1.07
ru	0.00	0.00	0.00	0.00	0.00
ap	.34	.36	.36	.53	.38
Others	1.18	1.19	.97	1.01	1.17
Total	99.50	99.26	99.28	99.41	99.41
Q+or+ab(%)	76.59	74.86	75.62	69.56	75.38

The samples are arranged from west to east. Western zone: U139, Epidote-biotite-sericite granodiorite, U138 (subvolcanic), diorite; U143, Biotite-sericite-epidote granodiorite; U145, Sericite-epidote-biotite granodiorite; U146, Sericite-epidote-biotite granite (sheared); U149, Muscovite-epidote-biotite granite; U150, Same as U149; U151, Leucocratic portion of gneissic granite.

ferric/ferrous ratio and magnetic susceptibility. Table 3 is a list of the main phase rocks of the Kate botholith indicating degree of shearing, from the strongest, augen gneissic texture to non-foliated granitoids. The magnetic susceptibility shows clearly inverse correlation with increasing shearing effects. This implies that the Kate granitoids are of the magnetite series originally, but during the regional shearing with successive elevation of temperature and supply of hydrothermal fluids, magnetite was broken down to other mafic minerals. Average bulk ferric/ferrous ratio of granitoids of similar silica contents from the western zone (U139–

of the Kate granitoids

U145j	U146j	U148Aj	U148Bj	U149j	U150j	U151j
63.38	57.78	73.07	76.32	69.61	73.53	75.35
.653	.917	.265	.129	.388	.358	.223
16.28	17.20	14.01	13.00	15.63	13.59	13.12
2.72	3.75	1.05	.65	.97	1.06	1.02
2.16	3.16	.40	.11	.97	.83	.14
.082	.113	.048	.022	.049	.031	.018
1.62	2.40	.32	.02	.61	.51	.04
4.44	5.36	1.33	.91	2.56	1.65	.53
3.63	3.64	3.06	3.21	3.36	2.16	2.24
3.28	2.95	5.49	5.13	4.61	5.07	6.89
.229	.321	.060	.022	.100	.039	.031
.79	1.58	.40	.26	.49	.70	.41
99.27	99.19	99.51	99.77	99.34	99.54	100.01
580	10	60	20	120	10	10
100	60	0	20	0	280	0
1.5	1.4	1.6	.7	1.3	1.6	.8
18.50	11.07	31.12	36.11	26.11	37.29	34.84
0.00	0.00	.76	.57	.70	1.64	1.08
19.41	17.45	32.43	30.30	27.23	29.99	40.73
30.72	30.81	25.87	27.18	28.46	18.32	18.96
18.42	21.88	6.23	4.36	12.04	7.92	2.42
.89	1.10	0.00	0.00	0.00	0.00	0.00
.67	.81	0.00	0.00	0.00	0.00	0.00
.13	.19	0.00	0.00	0.00	0.00	0.00
3.36	5.17	.79	.05	1.51	1.26	.10
.66	1.21	0.00	0.00	.43	.11	0.00
3.94	5.44	.68	.05	1.41	1.54	0.00
0.00	0.00	.58	.61	0.00	0.00	1.02
1.24	1.74	.50	.24	.74	.68	.33
0.00	0.00	0.00	0.00	0.00	0.00	.05
.53	.74	.14	.05	.23	.09	.07
.79	1.58	.40	.26	.49	.70	.41
99.27	99.19	99.51	99.77	99.34	99.54	100.01
68.63	59.33	89.42	93.58	81.80	85.59	94.53

Epidote-biotite-sericite granodiorite porphyry; U142, Sericite-epidote-biotite granodiorite; U144, Biotite-epidote-sericite grano-
quartz monzodiorite. Eastern zone, U148A, Muscovite-biotite granite, U148B, Aplitic band cutting U148A. Muscovite-biotite
Garnet-bearing biotite-muscovite granite. The mineral assemblage is described in increasing order of abundance.

146) is higher (3.4) in the augen gneissic granitoids than the less sheared granitoids (1.5, Table 3). Thus, with regards to oxygen fugacity, recrystallization took place under more oxidized condition than that of the original crystallization processes. Degree of shearing in the Bukoli granitoids is generally nil but locally noted (*e.g.*, NA2297). This sheared granite has the lowest value of magnetic susceptibility (Table 1), so that similar recrystallization-alteration history to that of the Kate granitoids may be expected in the Bukoli granitoids.

Table 3 Degree of shearing, magnetic susceptibility, ferric/ferrous ratio and sulfur isotopic composition of the main type rocks of the Kate batholith.

Sample no.	Degree of shearing	$\chi\times 10^{-6}$ emu/g	$K\times 10^{-5}$ SIU	Fe_2O_3/FeO (wt)	$\delta^{34}S$ (CDT) ‰
U139	strong	10	30	3.6	
U142	weak	200	800	2.1	+7.4
U144	nil	720	3000	1.4	+4.1
U143	strong	10	30	3.2	
U145	nil	580	2400	1.3	+3.9
U146	moderate	10	40	1.2	+1.0
U148A	strong	60	200	2.6	
U149	strong	120	400	1.0	
U150	strong	10	40	1.3	+2.3

The samples are arranged from west to east. Magnetic susceptibility is measured by two different types of device: χ (CGS unit emu/g) by KT-3; K (SI unit) by TH-1 magnetic susceptibility meter.

Chemical Characteristics

Chemical analyses were made by XRF method for 20 granitoids, and 3 greenstones. Glass-disc was prepared by mixing ignited rock powder of 0.3000 g with $Li_2B_4O_7$ flux of 0.3000 g and fusing them, following the method of OHMORI and OHMORI (1976). The measurement was done by the Philips X-ray spectrometer, System PW 1400 with the condition of Cr target, 40 kV and 75 mA. Data correction was made using H. HATTORI's computarized MP-2 program.

FeO was determined separately by conventional wet method. Ignition loss, which was measured during the ignition was converted to $H_2O\pm$, by subtracting the amount of oxygen converted from FeO to Fe_2O_3 during the ignition. Infrared absorption photometry after combustion, similar to TERASHIMA (1979), was employed for sulfur analysis. Tin was analyzed by atomic absorption spectrometry after extracting tin (IV) iodide with benzene (TERASHIMA, 1975). Isotopic composition of rock sulfur was also examined on some Kate granitoids using the techniques described in SASAKI *et al.* (1979) and SASAKI and ISHIHARA (1979). The results are listed in Tables 1, 2 and 3.

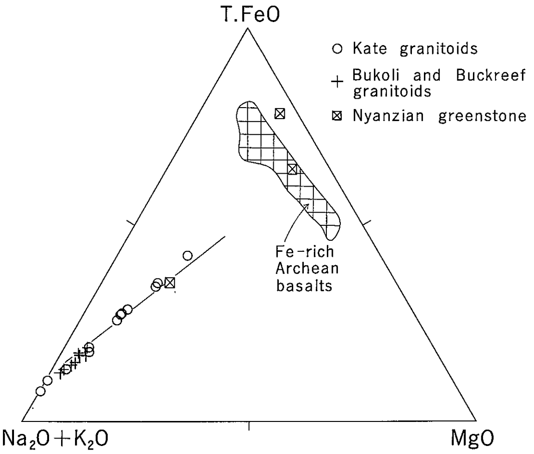


Fig. 6 MFA diagram (wt%) of the studied granitic and volcanic rocks. Straight line is the trend of average Japanese granitoids of ARAMAKI *et al.* (1972).

All the analyzed samples including 3 Nyanzian greenstones are plotted in MAF diagram (Fig. 6). In this diagram, two greenstones are plotted within or close to the area of Fe-rich Archean basalts (Basaltic Volcanism Study Project, 1981), whilst a plot of another sample (Bu 9-dacite) lies within the field of the granitoids. The Bukoli and Kate granitoids samples are plotted very close to the average trend of the calc-alkaline granitoids of Japan (ARAMAKI *et al.*, 1972).

In Fig. 7, major components of the Bukoli and Kate granitoids are plotted against the normative quartz(Q)+albite(ab)+orthoclase (or). Average compositions of the Japanese granitoids are also shown for comparison. Both the Bukoli and Kate granitoids have linear trends parallel to the Japanese granitoids in this diagram. It is surprising that such sheared rocks as the Kate granitoids show linear pattern for each component. This implies that the post-magmatic recrystallization described in the previous chapters is an isochemical reaction. As compared with the Japanese granitoids, the Tanzanian granitoids are high in Al_2O_3 and K_2O and Fe_2O_3/FeO ratios.

The Archean, Bukoli granitoids are different from the Proterozoic, Kate granitoids in the alkali ratio; the Bukoli rocks are rich in Na_2O and poor in K_2O. Within the Bukoli area, the Buckreef granodiorite is distinctly higher in Na_2O/K_2O ratio than the Bukoli granite. Since no alkali metasomatism has been recognized, the Buckreef, Bukoli and Kate granitoids had different magmatic evolution trends.

Because alkali variation is most distinct in the Tanzanian granitoids, ternary calcium-sodium-potassium diagram is prepared (Fig. 8). The Buckreef granodiorite is most sodic but is not as sodic as island-arc sodic granitoids (tonalites). The Bukoli granitoids are plotted close to the Japanese granitoids, while the Kate granitoids are much more potassic than the Japanese ones. K_2O/Na_2O ratio of the Kate granitoids increases with decreasing CaO content, while the Bukoli granitoids do not.

In ACF diagram (Fig. 9), all the Tanzanian granitoids fall in the field of I type of Chappell and White (1974). When the other parameters are concerned, all the Bukoli granitoids and the Kate granitoids of the western zone show I type characteristics *e.g.*, normative corundum less than 1 wt.% and Na_2O contents higher than 3.2 wt.% at ca. 5% K_2O. However,

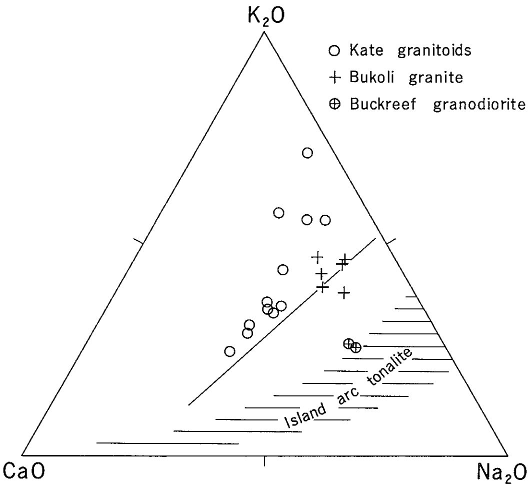
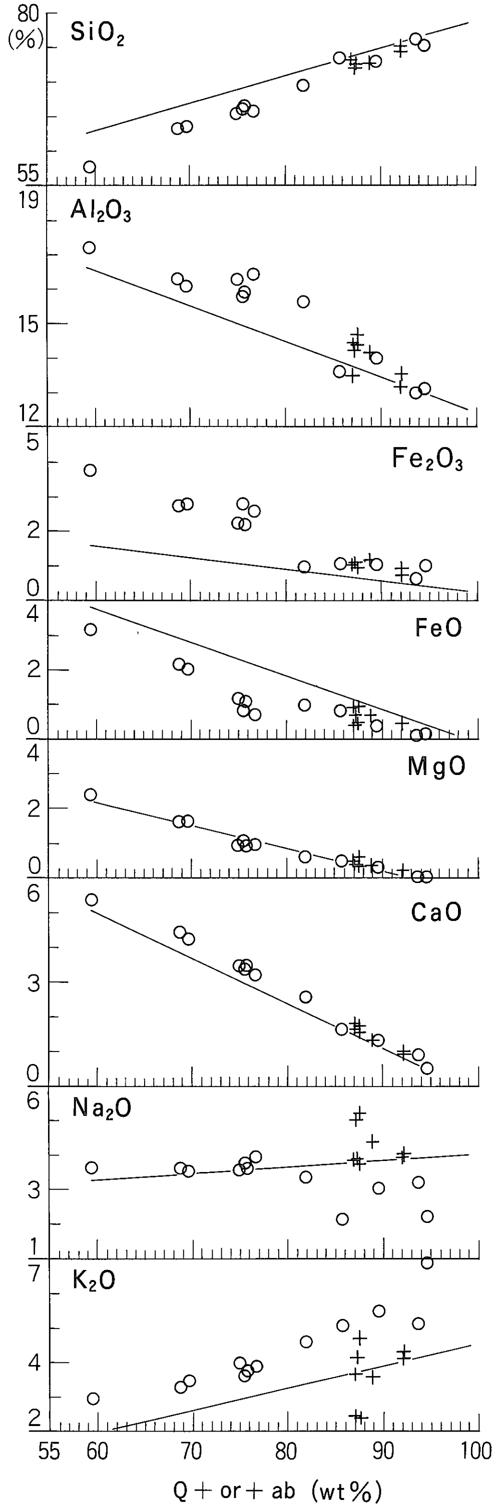


Fig. 8 Calcium-sodium-potassium diagram of the studied granitoids (wt%). Shaded is the area of the Tanzawa-type tonalite of Ishihara *et al.* (1976). Straight line is the trend of average Japanese granitoids of Aramaki *et al.* (1972).



←Fig. 7 Major elements plotted against normative quartz+albite+orthoclase (wt%). The symbols are the same as in Fig. 6.

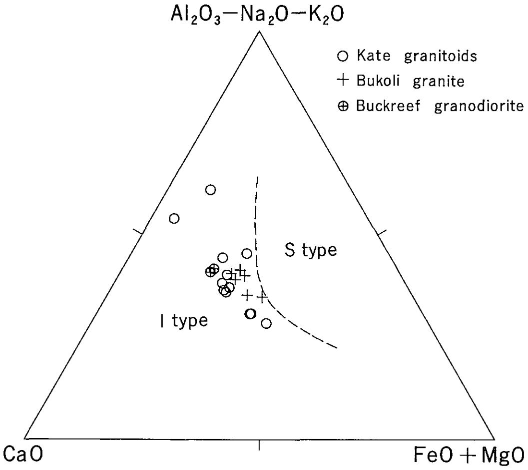


Fig. 9 ACF diagram of the studied granitoids (mole%). Boundary between I and S types is taken from TAKAHASHI *et al.* (1981).

biotite granite of the eastern zone of the Kate batholith has S type tendency on these components.

Sulfur content of the Tanzanian granitoids is generally low ($\leq$60 ppm S) for the majority of the samples (Tables 1, 2). It is worthy of note that the Archean granitoids (Bukoli and Buckreef) do not contain any sulfur (below detection limit for all samples except one with 10 ppm S); while the Proterozoic batholith at Kate contains higher sulfur content of up to 280 ppm. But the average is as low (50 ppm, n=11) as other magnetite-series granitoids (ISHIHARA *et al.*, 1983).

Sulfur isotopic analysis of five Kate rocks returns $\delta^{34}S$ (CDT) values of $+1.0$ to $+7.4^0/_{00}$ (Table 3), very similar to the values for Japanese granitoids of the magnetite-series (SASAKI and ISHIHARA, 1979). Shear-free, little deformed phases with high magnetic susceptibility values (U144, 145) have rather consistent $\delta^{34}S$ of ca. $+4^0/_{00}$, suggesting that this might be the representative of the original Kate sulfur. Post-magmatic events of the batholith may have influenced the original value to some extent, giving more variable isotopic composition in sheared or recrystallized granitoids (U142, 146, 150).

Tin content for the granitoids from both Archean and Proterozoic areas are extremely low (0.4 to 2 ppm S). The Archean granitoids, once more, show least Sn values especially the most sodic stock at Buckreef which is almost tin-free (Tables 1, 2). The Kate batholith shows slight Sn-enrichment, with the majority of samples having Sn-values between 1.6 and 1.9 ppm. Trace amounts of tin in granitoids is a good indicator of tin-mineralization in such intrusives (ISHIHARA and TERASHIMA, 1977). The Sn content of the Tanzanian granitoids is too low to warrant such mineralization speculations.

Genetic Consideration and Mineralization Potentiality

The data presented in the previous chapters on petrography, chemistry and magnetic susceptibility show that both the Archean and Proterozoic granitoids of Bukoli and Kate areas can be classified as magnetite series, particularly for the presence of magnetite in the least altered rocks and general high bulk ratio of Fe_2O_3/FeO. The ferric/ferrous ratio is not consistent with the magnetic susceptibility, especially on the Kate granitoids, unlike those of the typical magnetite-series.

This finding is compatible with the post-magmatic history of the Kate granitoids which underwent shear deformation and isochemical deuteric alteration whereby magnetite and ferro-magnesian and calcium bearing minerals have been converted to epidote-group minerals, hematite and ilmenite, which may have occurred even in more oxidized environment than the original magma. In this respect, the magnetic susceptibility data must be aided by petrographic and chemical data to come to a meaningful conclusion whether a given granitoid belongs to magnetite or ilmenite series.

In comparison with Japanese calc-alkaline granitoids of late Mesozoic to Cenozoic age, the much older Precambrian granitoids of Tanzania show no diagnostic differences on the variation diagrams of major elements. This finding may have far-reaching implications on the chemistry of granitic magmas which appears independent of time and space.

The Tanzanian granitoids from the two areas are generally hornblende free but show some chemical affinity, to I-type granitoids, although S-type characteristics are also noted locally in the granitoids, such as in the eastern part of the Kate batholith.

There are local differences between the Archean Bukoli and Proterozoic Kate granitoids. The Bukoli granitoids are more sodic and have uniform chemistry (*e.g.*, 72–75% SiO_2) showing narrow spread in variation diagrams of major elements, whereas the Proterozoic batholith is more potassic and has wide variation on the major chemistry (*e.g.*, 58–75% SiO_2). Thus, they are independent magma types generated and emplaced in different tectonic settings. Meta-volcanic rocks of the Nyanzian Greenstone Belt have no genetic relation to the Bukoli granitoids for they have different petrochemical characters, but volcanic rocks of the Kate area may be comagmatic with the granitoid in origin.

The post-magmatic episodes are quite different in both the granitoids. The Bukoli granitoids have experienced minimal tectonic deformation since they were emplaced. They post-date the Nyanzian orogenic event of deformation. On the other hand, the Kate granitoids which are late orogenic with respect to the Ubendian orogeny (2,000 Ma), were tectonically deformed, possibly soon after the emplacement. The deformational event was so severe that it led to partial or complete recrystallization and re-alignment of the rock-forming minerals to secondary assemblage of microcline-muscovite-epidote-sphene-hematite and augen-gneissic and protoclastic texture. Some elevated temperature is assumed for the complete recrystallization in the eastern zone.

With regard to mineralization potentiality of the granitoids, the data available indicate that both the Bukoli and Kate granitoids are capable of gold-basemetal mineralization, as they were formed by an oxidized type of magma and alterations, which favour this type of mineralization (Ishihara, 1981). Within the Bukoli area, the Buckreef stock may be higher level type than the Bukoli pluton, for the smaller exposure and distinct zoned plagioclase, providing a suitable environment for the mineralization.

There is little supporting evidence for tin granite existence in the studied areas, because the granitoids are of magnetite series and the tin contents are extremely low (below 2 ppm). According to Cahen and Ledent (1979), tin granites in central Africa have high initial $^{87}Sr/^{86}Sr$ ratio (0.7782) and their age is 976± 10 Ma, which is much younger than that of the Kate granitoids (1725±70 Ma). However, possibility of finding tin granite within the heterogeneous Kate batholith may not be ruled out absolutely, as the body is gigantic one and only a small part has been studied in this paper.

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タンザニア西部の2つの先カンブリア代花崗岩：始生代 Bukoli 岩群および原生代 Kate 底盤

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要　旨

ビクトリア湖南方に分布する始生代 Bukoli 岩群およびタンガニカ湖南東縁に露出する原生代 Kate 底盤の諸岩石について顕微鏡観察，帯磁率測定，主成分元素ならびに硫黄，スズの定量分析，硫黄同位体比測定などから記載と岩石学的検討を行った．両花崗岩類とも明瞭に磁鉄鉱系列に分類されるが，始生代の方が Na_2O/K_2O 比が高い．Kate 岩体の花崗岩類は貫入直後の激しい変形運動によって組織や鉱物組合せに規則的な変化を生じている．Fe_2O_3/FeO 比の増加と共に帯磁率は急激に低下する．

Bukoli 岩群中とくに Na_2O に富み，緑れん石—緑泥石変質が顕著な一群 (Buckreef 岩株)が，周辺の Nyanzian グリンストン帯中に見られる含金石英脈の形成に関係しているらしい．Kate 岩体の岩石も一般には金やベースメタルの鉱化を期待してもよい諸特性をもつが，現在までのところ鉱床として確認されたものは無い．北方の Karagwe—Ankolean 系中に見られるスズ—タングステン鉱化帯の延長を期待することも今のところ難かしい．

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