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Late Kibaran magmatism in Burundi

L. TACK*, P. DE PAEPE**, J. P. LIÉGEOIS***, G. NIMPAGARITSE*,
A. NTUNGICIMPAYE* and G. MIDENDE*

*Université du Burundi, Département des Sciences de la Terre, B.P. 2700, Bujumbura, Burundi
**Rijksuniversiteit Gent, Laboratorium voor Aardkunde, Krijgslaan 281, B-9000 Gent, Belgium
***Service de Géochronologie, Musée royal de l'Afrique centrale, B-1980 Tervuren, Belgium

Abstract - The Late Kibaran magmatism in Burundi is represented by 2 magmatic associations. Small alkaline granitoid plutons constitute the first one. In Central Burundi, they form a N-S alignment of 40 km. A new Rb-Sr 7 WR age of 1137 ± 39 M.a. (Ro = 0.7027 ± 0.0011; MSWD = 2.0), considered to date the emplacement of the granitoids, confirms a preliminary age of 1125 M.a. In Burundi and NW Tanzania, the second association is represented by an alignment of mafic and ultramafic intrusive bodies which form a prominent structure 350 km long and at least 25 km wide. The plutons have developed thermal aureoles.

In Central Burundi, the granitoids, as well as the mafic and ultramafic rocks, occur on both sides of a major N-S trending Late Kibaran shear zone. This suggests a genetic relationship, not only between the shear and the magmatism, but also between both magmatic associations. Recent fieldwork confirms this hypothesis as both mafic rocks and granitoids have been observed in continuity within a single massif. More field observations and laboratory research, however, are needed before we can propose a coherent geodynamic model.

Résumé - Le magmatisme tardi-kibarien du Burundi est representé par 2 associations magmatiques. De petits massifs de granitoïdes alcalins constituent la première association. Au centre du Burundi, ils sont alignés sur 40 km le long d'une direction méridienne. Un nouvel âge Rb-Sr sur 7 roches totales de 1137 ± 39 M.a. (Ri = 0,7027 ± 0,0011; MSWD = 2,0), considéré dater la mise en place des granitoïdes, confirme un âge préliminaire de 1125 M.a. Au Burundi et dans le NW de la Tanzanie, la seconde association est representée par un alignement de plutons basiques et ultrabasiques, constituant une structure majeure de 350 km de long sur au moins 25 km de large. Ces plutons sont entourés d'une auréole de métamorphisme thermique.

Au centre du Burundi, les granitoïdes et les roches basiques et ultrabasiques affleurent de part et d'autre d'une zone de cisaillement majeur, dirigée N-S et d'âge tardi-kibarien. Ceci suggère une relation génétique non seulement entre le cisaillement et le magmatisme, mais aussi entre les deux associations magmatiques. Des travaux de terrain récents confirment cette hypothèse puisque tant les roches basiques que les granitoïdes ont été observés en continuité au sein d'un seul massif. Toutefois, il est nécessaire de poursuivre les travaux de terrain et de laboratoire avant de proposer un modèle géodynamique précis.

INTRODUCTION

Recent literature with respect to the Late Kibaran of Burundi often refers to two well-defined but poorly studied magmatic associations. The first one is represented by alkaline granitoids, the second one by mafic and ultramafic intrusions (Tack and De Paepe, 1983; Tack, 1984; Klerkx *et al.*, 1987). The aim of this paper is to present new data on both associations and to update our knowledge on the problem.

THE ALKALINE GRANITOID INTRUSIONS

The granitoid plutons of Gitega, Makebuko and Bukirasazi, in Central Burundi (Fig. 1), are examples of this association (Tack and De Paepe, 1983). They are relatively small-sized (from ± 1 to ± 20 km² in area) and are lined up N-S over a distance of about 40 km. The granites invade Kibaran metasediments and the contact is either tectonic or intrusive. Field data suggest that the plutons are part of a larger body, which has been cut near its roof by the present topography.

Preliminary data on the mineralogy and chemistry of the granitoids of Bukirasazi and Makebuko are listed in Table 1. Less information is available with regard to the rocks of the Gitega pluton. However, the latter are macroscopically quite similar to those outcropping in the Makebuko pluton. An association of alkali granites (Bukirasazi) and more aluminous biotite-bearing syenogranites (Makebuko) (Table 1) is well-known in alkaline granitoid series (Jacobson *et al.*, 1958; Bowden and Turner, 1974; Lameyre and Bowden 1982; Ba *et al.*, 1985).

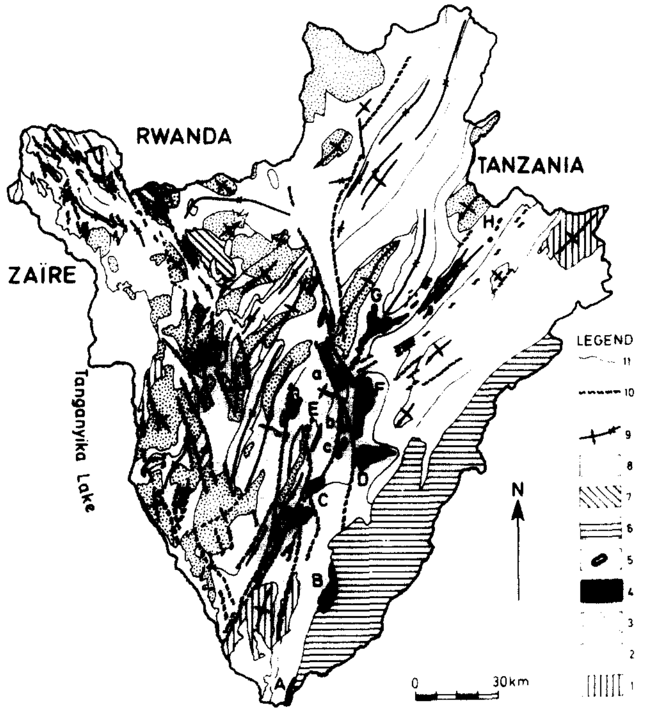

Fig. 1. Major structural and magmatic characteristics of the Kibaran belt in Burundi (after Klerkx *et al.*, 1987, slightly modified). 1. Archaean; 2. Burundian metasediments; 3. Kibaran granitoids; 4. Mafic and ultramafic intrusions; 5. Late Kibaran alkaline intrusions; 6. Malagarasian (Upper Proterozoic); 7. Upper Ruvubu alkaline plutonic complex; 8. Cainozoic; 9. Principal axes of upright folding (D2); 10. Principal Late Kibaran shear zones (D2'); 11. Stratigraphic limits and structural trends. Abbreviations refer to the location of the massifs: a: Gitega; b: Makebuko, c: Bukirasazi; A: Mugina; B: Songa; C: Rutovu ; D: Musongati; E: Waga; F: Mukanda-Buhoro; G: Nyabikere; H: Muremera.

Oval-shaped greyish quartz-bearing microsyenitic enclaves are common in the Makebuko granite. Their mineralogy is comparable to that of the host granite and the occurrence of acicular apatites suggests quench crystallization conditions (Didier, 1973). At one locality we found a light-coloured medium-grained granitic enclave which recalls the Bukirasazi granite. The igneous enclaves of the Makebuko pluton may be considered to express at least a cogenetic and probably a comagmatic differentiation at depth. Metasedimentary xenoliths do not occur in the Makebuko pluton. In the Bukirasazi massif xenoliths are only exceptionally observed.

In many places the plutons display nonpenetrative cataclasis, N-S trending foliation or even mylonitization. In the Makebuko massif a hastingsitic amphibole, saussuritized and sericitized oligoclase and bent or kinked brown biotite occur in the dynamically metamorphosed rocks. Biotite, when granulated, is brown greenish. Calcite and chlorite are really uncommon. In the Bukirasazi massif albite displaying deformation twins, granulated biotite associated with chlorite, hastingsitic amphibole, calcite and epidote are characteristic. Segregations of colourless to whitish, purple or blackish fluorite, specularite and some pyrite are frequently found in the Bukirasazi mylonites.

Table 1. Mineralogical and chemical characteristics of granitoids from Bukirasazi and Makebuko.

BUKIRASAZI	MAKEBUKO
dark and light-coloured medium grained alkali granites grading into quartz-bearing alkali syenites	pink to greyish coarse-grained syenogranites
heterogeneous, locally with a N-S trending magmatic layering	rather homogeneous
microperthite, occasionally with Carlsbad twinning, predominates albite	microperthite, sometimes with Carlsbad or tartan twinning, predominates subhedral oligoclase (15-25 % An), which exceptionally is zoned
hypersolvus characteristics	subsolvus characteristics
Very dark brown biotite (lepidomelane ?), in association with opaques, is omnipresent	brown biotite is omnipresent
a calcic amphibole (hornblende), often rimmed by a green-bluish K-hastingsite(*), occurs in some rocks	
zircon, allanite and fluorite are accessory minerals	zircon and allanite are accessory minerals
in contrast with the other Kibaran granitoids of Burundi, muscovite and tourmaline are systematically lacking	
62 % < SiO_2 < 76 % (**)	72 % < SiO_2 < 76 % (***)
molecular $Al_2O_3/Na_2O + K_2O + CaO < 1,1$	
mildly peralkaline: molecular Al_2O_3 is slightly less than $Na_2O + K_2O$	Metaluminous: molecular Al_2O_3 > $Na_2O + K_2O$
Na_2O > 4,3 %	2,3 % < Na_2O < 2,7 %
K_2O is usually higher than 4 % and often superior to 5 %	4,8 % < K_2O < 5,7 %
Diopside and sometimes even low percentages of aegyrine in the norm (CIPW)	Low percentages of diopside, or otherwise less than 1 % corundum in the norm (CIPW)

(*) microprobe data (anal. J. Wautier, CAMST-UCL)
(**) based on 9 major element analyses (anal. J. Van Hende, RUG)
(***) based on 6 major element analyses (anal. J. Van Hende, RUG)

A preliminary Rb-Sr whole-rock age of 1125 ± 25 M.a. (Ro = 0.7077 ± 0.0021; MSWD = 2.0) has been reported for the plutons of Gitega, Makebuko and Bukirasazi (Klerkx *et al.*, 1987). A Rb-Sr 7 whole-rock isochron, obtained for rocks coming exclusively from the massif of Bukirasazi, yielded an age of 1137 ± 39 M.a. (Ro = 0.7027 ± 0.0011; MSWD = 2.0) (Fig. 2 and Table 2). These ages are considered to be emplacement ages and they postdate the major D2-deformation phase of the Kibaran of Burundi (around 1185 M.a.) (Klerkx *et al.*, 1987).

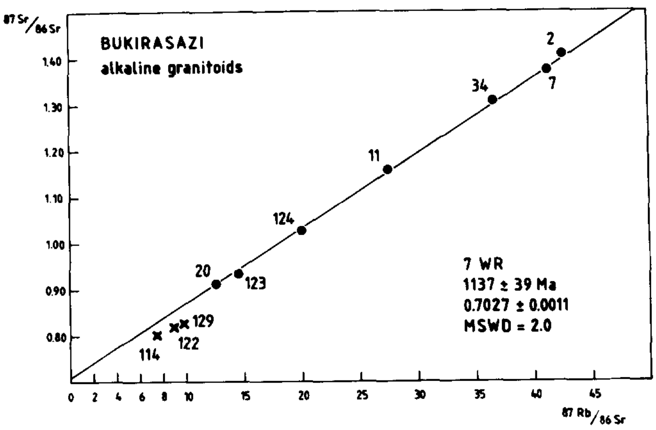

Fig. 2. Isochron of the alkaline granitoids of the Bukirasazi massif.

Table 2. Rb-Sr isotopic data of the Bukirasazi massif

Sample	Rb(ppm)	Sr(ppm)	$^{87}Sr/^{86}Sr$	±2σ	$^{87}Rb/^{86}Sr$
Gi 2	183	13.28 (*)	1.40348	0.00016	42.62
Gi 7	225	16.34 (*)	1.37049	0.00005	42.45
Gi 11	224	24.60 (*)	1.15859	0.00007	27.52
Gi 20	208	49.2	0.91174	0.00005	12.48
Gi 34	207	17.42 (*)	1.30627	0.00005	36.41
Gi 114	151	59.6	0.79777	0.00005	7.396
Gi 122	223	72.6	0.81863	0.00006	8.985
Gi 123	213	43.4	0.93092	0.00005	14.51
Gi 124	228	33.9	1.02563	0.00005	20.07
Gi 129	209	62.2	0.82453	0.00005	9.835

Rb and Sr concentrations were determined either by XRF (anal. Léger MRAC) or by isotopic dilution (*).
The errors on the $^{87}Rb/^{86}Sr$ ratios are 2 %.
Mean value obtained on NBS standard 987: 0.710235 ± 0.000026.
Normalisation for $^{86}Sr/^{88}Sr = 0.1194$
$\lambda^{87}Rb = 1.42\ 10^{-11}\ a^{-1}$.
Isotopic ratios were measured on the **Varian Mat** 260 mass spectrometer of the Centre Belge de Géochronologie. The ages and initial ratios were calculated following the method of Williamson (1968). All the errors are quoted at the 2σ m level.

They further show that the postulated Pan-African ages (Tack and De Paepe, 1983) of the Central Burundi granitoids, based on petrographic similarities with the Upper Ruvubu granitoids (Tack *et al.*, 1984), were erroneous. The low $^{87}Sr/^{86}Sr$ initial ratio of the rocks from the Bukirasazi massif suggests a deep origin for the pluton. This is in contrast with the older intracrustal granitoid associations of the Kibaran of Burundi (Fernandez-Alonso, 1986; Fernandez-Alonso *et al.*, 1986; Klerkx *et al.*, 1984; Klerkx *et al.*, 1987).

Three points lie below the isochron shown in Fig. 2. Although no unequivocal explanation can be given, it is interesting to note that these points give an age of 815 ± 156 M.a. (Ro = 0.712 ± 0.018; MSWD = 1.7) which may correspond, either to an early Pan-African tectonic phase already known elsewhere in Burundi (Tack *et al.*, 1984) or to an event recorded in the Songa mafic pluton (K-Ar age of 900 M.a.; Cahen *et al.*, 1984) discussed below. In both cases, this poorly defined "age" may indicate a tectonic reactivation. The latter has not affected the texture of the rock but appears on a geochemical level. As the rocks located below the isochron have the lowest Rb/Sr ratios tectonic features may be involved. This point will be discussed in a next paper.

THE MAFIC AND ULTRAMAFIC INTRUSIONS

Rocks of this association build up the following mafic and ultramafic intrusive bodies of Southern, Central and Eastern Burundi: the plutons of Mugina, Songa, Rutovu, Musongati, Waga, Mukanda-Buhoro, Nyabikere, Muremera and other minor intrusions (Fig. 1) (Tack, 1984). They have imprinted thermal aureoles on the enclosing Kibaran metasediments (andalusite schists, garnet-chloritoid-biotite hornfels, etc.). Emplacement as tectonic slices of these mafic and ultramafic rocks is thus precluded. In some places the intrusions seem concordant with the Kibaran folds (D2- phase). They have been emplaced along an alignment trending NNE-SSW in Southern Burundi but grading progressively into a N-S direction in Central Burundi. In the eastern part of the country the direction is NE-SW (Fig. 1). In this part of the belt, the latter corresponds with the typical Kibaran direction. Similar plutons extend northeastwards up to Lake Victoria in Northern Tanzania (van Straaten, 1984). The alignment of these plutons forms a prominent structure approximately 350 km long and about 25 km (exceptionally 50 km) wide.

The plutons are composed of one or several of the following rock types: (leuco)gabbros, (leuco)norites, anorthosites, pyroxenites, peridotites, dunites, etc. They sometimes display features of layered intrusions and may bear mineralisations of Fe, Ti, V, Ni, Cu, Co and elements of the Pt group (Niyondezo, 1984; Jedwab, 1987). In part of the Mukanda-Buhoro massif (Nimpagaritse, 1986) the main rock types (gabbronorite and anorthosite) contain adcumulate plagioclase (An_{55}-An_{65}), interstitial iron-rich pyroxene (Fs/En = 55/39 for pigeonite and hypersthene, and 32/31 for augite) and/or V-bearing ilmenomagnetite. In the Songa massif (Sahinguvu, 1985) the most widespread rock is a norite, whereas leuconorite, anorthosite and gabbro occur in very subordinate amounts. These rocks constitute plagioclase cumulates crystallizing in the sequence gabbro-norite-leuconorite-anorthosite.

The mafic and ultramafic intrusions, as well as the thermal aureoles, are locally affected by non-penetrative cataclasis, foliation or even mylonitization which developed a characteristic greenschist-facies mineralogy (chlorite, serpentine, tremolite, sericite, calcite, epidote, albite, quartz, etc.).

A provisional Rb-Sr value of 1236 ± 70 M.a. (Ro = 0.70298 ± 0.00012; MSWD = 15), based on 2 phlogopite-calcite pairs from a core drilled into the Mukanda-Buhoro massif, has been obtained (Table 3). Because of the poor quality of this four-points alignment, one has to be very careful in the interpretation of this result, but it is reasonable to admit that the analysed minerals have a Kibaran age. Rocks of the Songa massif yielded a minimum K-Ar age of 900 M.a. (Cahen *et al.*, 1984).

RELATIONSHIPS BETWEEN THE MAGMATIC ASSOCIATIONS

A spatial relationship between the 2 magmatic associations in Central Burundi has been reported previously (Tack, 1984). The granitoid (Gitega, Makebuko and Bukirasazi) and mafic-ultramafic plutons (Mukanda-Buhoro and Musongati) occur on both sides of a major N-S trending shear zone (Fig. 1) ("Tshene zone") which affects Kibaran metasediments (Radulescu, 1981; Theunissen, 1984; Ladmirant and Waleffe, 1984; Ntungwanayo, 1985; carte géologique du Burundi, feuille Mwishanga). A provisional and not very precise Rb-Sr age on mylonites from a core drilled into a shear zone in southwestern Burundi (Bururi) has given 1095 ± 111 M.a. (Ro = 0.756 ± 0.022; MSWD = 0.05) indicating that the shear is a Kibaran event. In fact, the shear is now considered to represent the latest Kibaran structural event (D2'-phase) in Burundi (Theunissen, 1984; Klerkx *et al.*, 1987).

As both magmatic associations may be themselves locally deformed concordantly with the shear zone, we found it reasonable to infer an emplacement of the magmatism penecontemporaneous with and due to the shear event, the granitoids representing, according to this hypothesis, differentiation products of the mafic and ultramafic rocks.

Table 3. Rb-Sr isotopic data of minerals from the Mukanda-Buhoro massif.

Sample F54	Rb (ppm)	Sr (ppm)	$^{87}Sr/^{86}Sr$	± 2σ	$^{87}Rb/^{86}Sr$
Phl.1	332(*)	616(*)	0.73017	0.00006	1.563
Phl.2	314(*)	630(*)	0.72891	0.00006	1.445
Calc. 1 (1,5° NM)	5.51(*)	6812(*)	0.70283	0.00005	0.00234
Calc. 2 (1° NM)	10.74(*)	4052(*)	0.70331	0.00005	0.00767

Rb and Sr concentrations were determined (anal. Léger, MRAC) by isotopic dilution (*).
The errors on the $^{87}Rb/^{86}Sr$ ratios are 2 %.
Mean value obtained on NBS standard 987: 0.710235 ± 0.000026.
Normalisation for $^{86}Sr/^{88}Sr$ = 0.1194.
$\lambda\,^{87}Rb = 1.42\ 10^{-11}\ a^{-1}$.
Isotopic ratios were measured on the **Varian Mat** 260 mass spectrometer of the Centre Belge de Géochronologie. The ages and initial ratios were calculated following the method of Williamson (1968). All the errors are quoted at the 2σ m level.

Recent detailed mapping of a satellite pluton of the Bukirasazi massif (Fig. 1) confirms this hypothesis. Indeed, in this small pluton (1 to 2 km² in area) both magmatic associations have been observed in continuity in the field. Gabbros (± 30 % of the massif) are associated with quartz-bearing syenites (± 50 %) and granites (± 20 %). The rocks outcropping in the massif are identical to those characterizing both described magmatic associations.

CONCLUSIONS

Some important conclusions with respect to both magmatic associations may be drawn:

- the mafic, ultramafic and granitoid rocks in Central Burundi may be cogenetic, the latter representing differentiation products of the former; both magmatic associations have a deep origin related to tensional features which developed on a lithospheric scale; in the present state of knowledge we cannot exclude that the tensions lasted for a period of time and that, consequently, different magma chambers may have formed; the granitoids are at least partially mantle-derived and crustal contamination was probably not very important (Ro = 0.7027 ± 0.0011); further geochemical investigations have to be carried out;
- the age of the granitoids (1137 ± 39 M.a. for the Bukirasazi pluton) dates approximately or slightly postdates the mafic and ultramafic magmatism; with respect to the evolution of the Kibaran belt in Burundi. This age is a Late Kibaran age; the shear event (D2'-phase) has approximately the same age; later reactivation of the shear is possible and even likely.

FINAL CONSIDERATIONS

The link observed between both magmatic associations in Central Burundi may exist both in other parts of the country and elsewhere in the Kibaran belt. This is confirmed by data from the Rutovu area (Fig. 1), where granitoids are associated with mafic rocks (Claessens pers. commun.), and from the Nyabikere area (Fig. 1), where small exposures of granitoids have been mapped in association with mafics and ultramafics (Karayenga, in press). More fieldwork has of course to be carried out in order to get more details about the relationship between both associations.

It should not be surprising to find one or some of the previously described magmatic rocks in the vicinity of other shear zones of the Kibaran belt. We identified, for an example, a sheared and very weathered syenitic rock sample in northwestern

Burundi (Butahana area). Other occurrences have been reported more to the north in Rwanda (Nyungwe area) (Franceschi Pers. commun.). In southwestern Burundi (Nyanza-Lac area), more or less retromorphosed ultramafic rocks associated with cataclastic or mylonitic zones have already been described (Adams, 1986; Sintubin, 1986; carte géologique du Burundi, feuille Makamba).

Though a general geodynamic interpretation of both magmatic associations and of the shear event has already been proposed in the framework of the crustal evolution of the northern Kibaran belt in Eastern and Central Africa (Klerkx *et al.*, 1987), it is still premature to present a complete model. However, we are now sure that after a rather long period of bimodal magmatism, involving an important crustal component (1350-1260 M.a. and around 1185 M.a.; Klerkx *et al.*, 1987), we are dealing around 1140 M.a. with mantle-derived magmatism with striking alkaline characteristics. This suggests new geodynamic constraints and a possible marker for the end of the Kibaran orogeny in Burundi. Indeed, alkaline magmatism associated with transcurrent faults marks the end of the orogeny in several more recent belts: the Pan-African belt of the Adrar des Iforas (Liégeois and Black, 1987; Liégeois *et al.*, 1987) and of Saudi Arabia (Harris, 1982; Harris, 1985; Harris and Marriner, 1980), the Hercynian belt of Corsica (Bonin *et al.*, 1978) and the Alpine belt of Turkey and Iran (Innocenti *et al.*, 1982).

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