Nummer 3

THE ALKALINE PLUTONIC COMPLEX OF THE UPPER RUVUBU (BURUNDI) : GEOLOGY, AGE, ISOTOPIC GEOCHEMISTRY AND IMPLICATIONS FOR THE REGIONAL GEOLOGY OF THE WESTERN RIFT

LE COMPLEXE ALCALIN DE LA HAUTE RUVUBU (BURUNDI) : GEOLOGIE, AGE, GEOCHIMIE ISOTOPIQUE ET IMPLICATIONS POUR LA GEOLOGIE REGIONALE DU RIFT OCCIDENTAL

L. Tack, P. De Paepe, S. Deutsch and J.-P. Liégeois

ABSTRACT

The alkaline plutonic complex of the Upper Ruvubu is a high-level Pan-African intrusion emplaced into Kibaran rocks. Three units have been distinguished : (1) an older unit composed of an association of olivine gabbros, diorites, quartz-bearing syenites and granites with gradual and progressive transitions among these rock types; (2) a younger core of foid-bearing syenites in which four main textural types have been recognized; (3) an underlying carbonatite body only known by drilling and not studied in the present paper.

The outer unit is affected by a N-S foliation of variable intensity whereas the central foid-bearing syenites are only locally foliated and therefore considered as tardi-tectonic.

Rb-Sr on whole-rock and U-Pb on zircon studies show that the emplacement of the complex occurred around 740 Ma with a Rb-Sr rehomogenization at about 700 Ma. $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ initial ratios point to a slightly depleted mantellic source (probably the asthenospheric mantle) without upper crustal contamination.

Finally attention is drawn on the particular spatial distribution along the rift of 19 alkaline complexes with comparable ages, rock types and anorogenic features implying that the present-day Western Rift area was already a zone of weakness in late Precambrian times.

RESUME

Le complexe plutonique alcalin de la Haute Ruvubu est une intrusion pan-africaine superficielle mise en place dans les roches du tectogène kibarien. Trois unités ont été distinguées : (1) l'unité la plus ancienne est externe et composée d'une association de gabbros à olivine, de diorites, de syénites quartzifères ainsi que de granites; elle est caractérisée par des passages graduels et progressifs d'un type de roche à l'autre; (2) un noyau plus jeune de syénites feldspathoïdales dans lequel quatre types texturaux principaux ont été reconnus; (3) un corps carbonatitique connu uniquement par sondage et hors du cadre du présent article.

Une foliation N-S d'intensité variable affecte fortement l'unité externe et très localement les syénites foïdales centrales qui sont donc considérées comme tardi-tectoniques.

L'étude géochronologique (Rb-Sr sur roches totales et U-Pb sur zircons) indique que le complexe s'est mis en place vers 740 Ma et a été réhomogénéisé par une phase thermique vers 700 Ma.

Les rapports initiaux $^{143}Nd/^{144}Nd$ et $^{87}Sr/^{86}Sr$ suggèrent une source mantélique légèrement appauvrie, probablement asthénosphérique, sans contamination par la croûte inférieure.

Enfin, l'attention est attirée sur la distribution spatiale particulière le long du rift d'un ensemble de 19 complexes alcalins comparables tant par leur âge et leurs associations lithologiques que par leurs caractéristiques anorogéniques. Ceci implique que la région du Rift Occidental actuel représentait déjà une zone de faiblesse à la fin du Précambrien.

INTRODUCTION

A few years after the discovery (Delhaye & Salée, 1928) of «dioritic» rocks in the source region of the Ruvubu river, in north-west Burundi, some petrographical descriptions and chemical analyses of rocks from this area were published (Thoreau, 1931; 1932). The reported samples included nepheline syenite, nepheline monzonite and a grey aphanitic rock supposedly derived from a nepheline syenite by a process of recrystallization. According to Thoreau (1932) these rocks belonged either to a single intrusion or to a series of small intrusive bodies to which the name of «massif alcalin de la Haute-Ruvubu» was given. This author also noted a striking similarity between the rocks from the Upper Ruvubu region and those exposed in Zaïre in the nepheline-syenite Rutshuru massif (Lacroix & Delhaye, 1927), later on renamed Kirumba massif (Denaeyer, 1959). With respect to the latter, outcropping some 200 km more to the north, the Upper Ruvubu massif is located on the opposite eastern scarp of the Western Rift.

Geological reconnaissance work in the Upper Ruvubu region by Denaeyer (1959) was followed by two years of intermittent field work carried out by Antun (1960-1961). More than 600 exposures were visited in the area by Antun and gave him the opportunity to collect and to describe in the field some 800 rock samples including gabbros, diorites, monzonites, quartz-bearing syenites, granites, dolerites, feldspathoidal syenites (with nepheline, sodalite and/or cancrinite), amphibolites and gneisses. With the exception of a general account on the geology of the Upper Ruvubu region and the neighbouring area (Antun, 1965a), the field observations and notes of this worker unfortunately remained unpublished. In his opinion the saturated and foid-bearing syenites, as well as the other alkaline igneous rocks exposed in the area, formed part of one and the same large and complex intrusive body. Later investigators generally adopted the name of syenite massif to cover the whole intrusion. Cahen *et al.* (1979) gave a preliminary age of 774 ± 88 Ma for this massif. Although this age was only based on a Rb-Sr 3 point -isochron a genetic relationship between the alkaline complex and the Cenozoic volcanic provinces located along the Western Rift had to be ruled out (Tack & De Paepe, 1981).

In recent times random observations and sampling were carried out in the Upper Ruvubu region during systematic geological mapping of Burundi (Claessens, Dreesen, Karayenga, Radulescu, Theunissen & Waleffe; Carte géologique du Burundi, feuille Ngozi, 1:100.000, 1983). A UNDP-project was initiated to investigate the economic potential of the Upper Ruvubu area and produced several reports and mineral exploration maps in most cases not yet published (Projet de Recherches Minières, ONU-PNUD; Scarlat, 1977; Smejkal, 1979; Radulescu, 1981; Rombouts, 1982). One of their major findings was the discovery in the subsoil of Matongo of a carbonatitic body. All these recent research programs were conducted under the supervision and authority of the «Ministère des Travaux Publics, de l'Energie et des Mines du Burundi».

About seven years ago one of the authors of the present paper (L.T.) started a systematic survey of the Upper Ruvubu alkaline intrusion on a scale 1/25.000. Since 1977 more than 1200 observation points were visited.

In a preliminary account on the foidal syenites of the intrusion Tack & De Paepe (1981) outlined the general structure of the massif and recognized the following units :

1. An older unit, in which texturally and compositionally the rocks are exceedingly variable (=outer unit),
2. a younger central core of foid-bearing syenites,
3. a carbonatitic body (only known by drilling).

In 1982 Tack & De Paepe presented a geological map of the whole massif which they called the **Upper Ruvubu Alkaline Plutonic Complex (URAPC)** as a reminder of the name proposed earlier by Thoreau (1932). The aim of this paper is to give a detailed account of our contribution to the

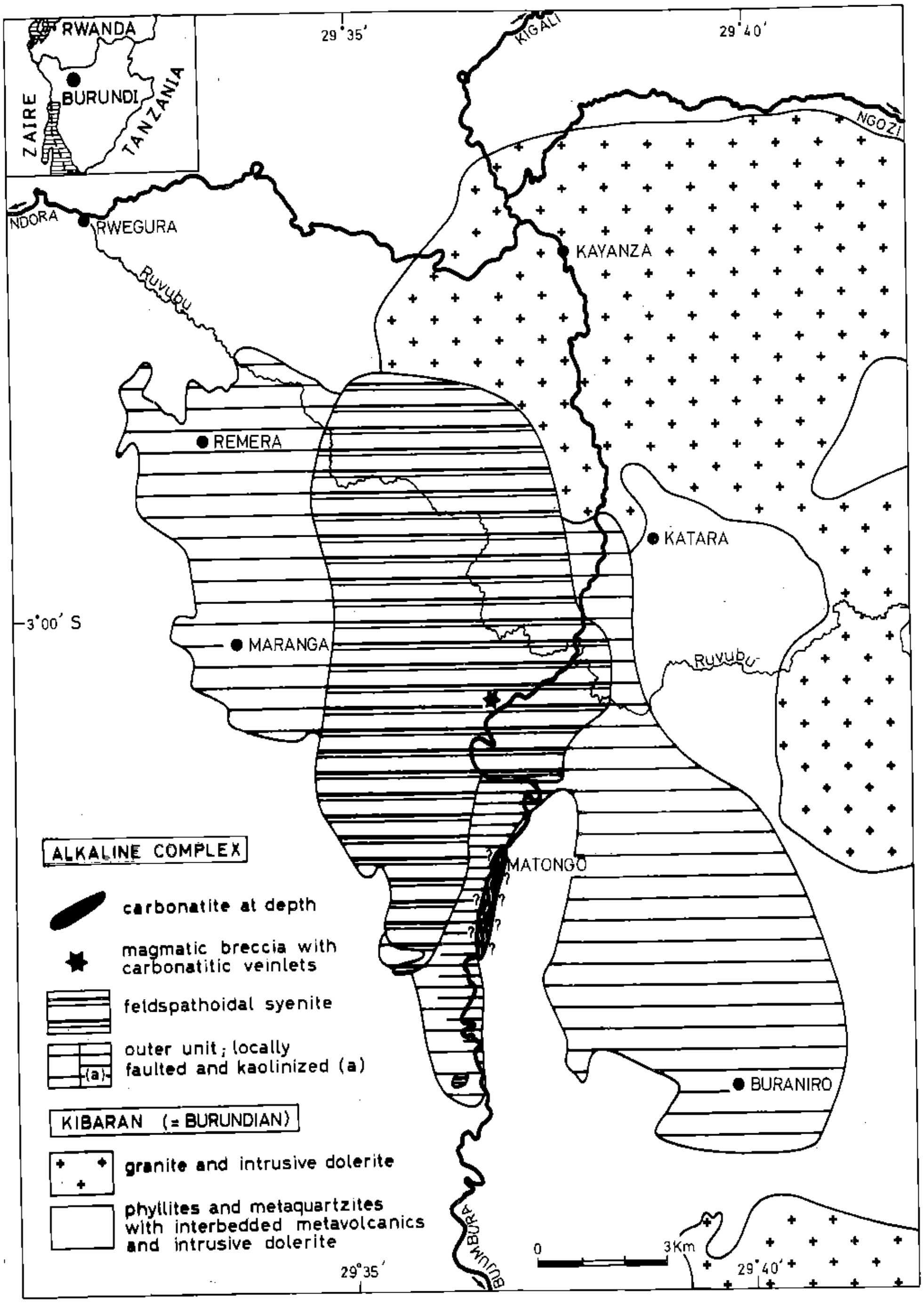

Fig. 1.- Location of the different units of the alkaline complex.

knowledge of this massif and to draw attention on other examples of Pan-African alkaline magmatism developed on a regional scale in the vicinity of the Western Rift.

REGIONAL GEOLOGICAL SETTING

The URAPC is discordantly intruded into various Precambrian rocks of Kibaran (= Burundian) age (fig. 1). Along its western border the country rocks consist of phyllites, metaquartzites and interbedded metavolcanics (Ntungicimpaye, 1981; 1983; 1984a,b). These rocks, of either greenschist or amphibolite facies, form part of an extensive belt of Burundian formations which occupy the greater part of NW Burundi. N and NE of the complex, in the neighbourhood of Kayanza, the Burundian sequence is invaded by a sharply defined batholith of two-mica granite. This Kayanza granite is calc-alkaline (Claessens *et al.*, 1981), tourmaline-rich, more or less foliated and usually porphyritic. Flow textures are sometimes suggested by the parallel arrangment of the feldspar phenocrysts. A Rb-Sr whole rock age of 1330 ± 30 Ma has been obtained for this granite (Klerkx *et al.*, 1984) which represents therefore a rather early event in the Kibaran history of Burundi. Pegmatites, composed of feldspar, quartz, muscovite, biotite and more exceptionally with black tourmaline, cassiterite and garnet, as well as a few aplites are associated with the granitic body.

The Burundian quartzites which border the Kayanza batholith are often tourmalinized or muscovitized. Xenoliths of metasediments have been observed in the granite. The emplacement of the batholith was associated with a basic magmatism (Klerkx, 1983; Klerkx *et al.*, 1984; Ntungicimpaye, 1984a,b). This magmatic activity resulted in the formation of a whole series of doleritic and amphibolitic dykes and sills which occur over the region cutting Kibaran rocks. An important dolerite sill is emplaced at the contact of the batholith with the surrounding quartzites of Ruganza (Carte Géologique du Burundi, feuille Ngozi, 1983).

The Kayanza granite occurs in a major Kibaran antiform structure while the metasediments and interbedded extrusive rocks define a synform structure surrounding the granite dome. The general tectonic evolution of the Kibaran in Burundi has been described in detail by Theunissen & Klerkx (1980), Theunissen (1984) and Klerkx *et al.* (1984).

In the Upper Ruvubu area the Burundian metasediments are characterized by a S1-foliation which is parallel to the bedding (So) of the original sediments. In the granites and basic rocks of the Kibaran a locally developed foliation (S1) - when observable - is systematically concordant with the S1-foliation of the surrounding metasediments. Thus, the strike of the S1-foliation displayed by the Burundian rocks is not constant. According to its location in the synform structure it varies from NNW in the western part of the studied area, through N-S to approximately E-W in the vicinity of Kayanza (fig. 2).

GENERAL STRUCTURE AND FIELD RELATIONSHIPS (figs. 1,2 & 3).

The URAPC covers approximately 154 km^2. Its shape is elongate, with a northwest-southeast axis (from Remera to Buraniro) of about 24 km long and a maximum width of 10 km. Besides the carbonatitic body of Matongo, which is hidden below the present-day erosional surface, the two exposed units of the complex cover respectively 91 km^2 (outer unit) and 63 km^2 (foid-bearing syenites).

In the north-western and central part of the URAPC a good correspondance was found between the outermost limit of the complex as suggested by geophysical prospection (magnetic and radiometric anomalies) (Peric, pers. comm.) and our own field data. In the south-eastern part of the complex comparable geophysical information is unfortunately lacking. Aerial photographs were not helpful for differentiating the various rocks within the URAPC.

The central position of the foidal-syenite body and the composition of the dykes and xenoliths of the complex show that the feldspathoidal syenites are younger than the rocks of the outer unit. The orientation of the older unit (fig. 2) is NW-SE and roughly parallel to the strike of the S1 foliation which characterizes the Burundian rocks in the western part of the area. As the younger foid-bearing syenites invaded the central part of the unit two main zones may now be recognized : a northernmost zone extending from north of Remera to the vicinity of Maranga; a larger zone almost entirely

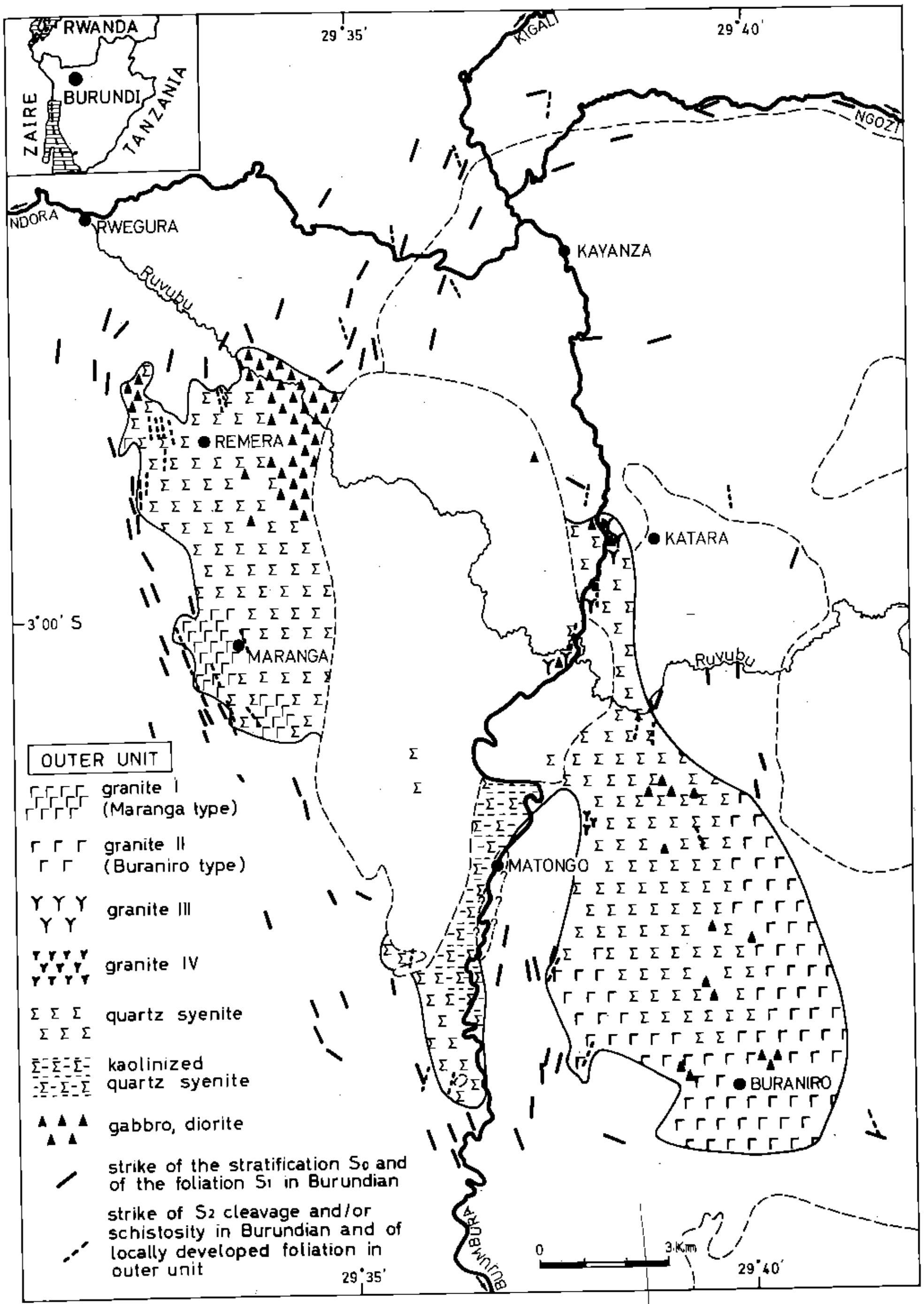

Fig. 2.- Distribution of the main rock types constituting the outer unit.

located east of the main road connecting Bujumbura with Kayanza extends from Katara to Buraniro. In the vicinity of Matongo the latter is affected by a strong supergene kaolinization.

South-east of Matongo a roof pendant of Burundian metasediments is preserved.

The younger foid-bearing syenitic unit (fig. 3) is located in the core of the complex. Its shape is elliptical, with the main axis of the ellipse oriented N-S. The longer and the shorter axes measure respectively 14 km and 6.5 km. A second small satellite body (200 m in diameter) is situated south of the main foidal intrusion. The foidal syenites are better exposed than the rocks of the outer unit. Volcanic rocks associated with the URAPC are apparently absent.

MAIN ROCK TYPES

The outer unit (fig. 2)

The rocks of this unit comprise of an intimate association of plutonic rocks ranging from olivine gabbros and diorites, through quartz-bearing syenites to granites. Clear-cut limits between the above mentioned rock types are not observed in the field not only for lack of exposures but mostly by the gradual and progressive transition from one rock type to another. In such transition zones saturated monzonites, quartz-bearing diorites, monzodiorites and monzogabbros, for instance, have been recognized. The study of the dykes and the xenoliths found in this unit indicate a classic differentiation sequence from a more basic parent to an acid residuum. There is also clear evidence for alkali autometasomatism of variable intensity. In some exposures indeed untransformed and strongly metasomatised rocks may coexist.

Despite the great heterogeneity, the rocks fall into a number of subunits. Each of them is characterized by the dominance of a certain rock type. From a petrographical point of view it appears that some subunits are quite homogeneous while others are more heterogeneous. As indicated below their regional distribution is unequal with the quartz syenites as the commonest variety :

granite I (Maranga type) :	3 km²
granite II (Buraniro type) :	24 km²
granite III :	<1 km²
granite IV :	<1 km²
quartz syenite :	56 km²
gabbro-diorite :	6 km²

The Maranga granite (granite I) is a hololeucocratic medium-grained rock which may contain large embayed crystals of euhedral quartz. The other constituents include microperthite, albitic plagioclase and small amounts of biotite and opaque ore (usually hematite). The granite is often foliated and mylonitised and is furthermore characterized by the presence of numerous quartz segregations and veins. This granite also occurs locally west of Remera on the edge of the massif.

The Buraniro granite (granite II) is exposed in the SE part of the URAPC. It is the most widespread of the complex. The rock is slightly pinkish and coarse-grained with microcline- perthite, quartz, albitic plagioclase and biotite as essential constituents. In some exposures one notes the presence of large euhedral high-temperature quartz crystals as well as a brown to bluish-green amphibole. The rock is usually unfoliated and only in a few cases crushing of the minerals was observed. With decreasing quartz content granite II passes progressively into pinkish quartz syenites. As shown by fig. 2 the Buraniro granite displays a sickle-shaped outline. Although this may suggest the presence of an annular intrusion this is not supported by the field observations. Sharply defined, cross-cutting contacts with the surrounding igneous rocks are indeed lacking. On the contrary, the granites grade progressively into quartz syenites, and gabbro-diorite occurrences appear within both the granites and the quartz syenites.

Granite III is the less common one and is outcropping in a small oblong zone located west of Katara. The rock also occurs as xenoliths in the foid-bearing syenite mass. With the exception of a higher quartz content the mineralogical composition of this granite is identical to that of the quartz syenites described below.

Granite IV is found a short distance to the NE of Matongo. The essential minerals are albite, microperthite, quartz and biotite. Albite is much more common than in any other granite of the complex. Although the grain size of this granite is quite variable it appears that the rock is usually medium-grained.

Quartz-bearing syenites constitute nearly two third of the outer unit. They are generally pink and medium to coarse-grained. Locally fine-grained se-

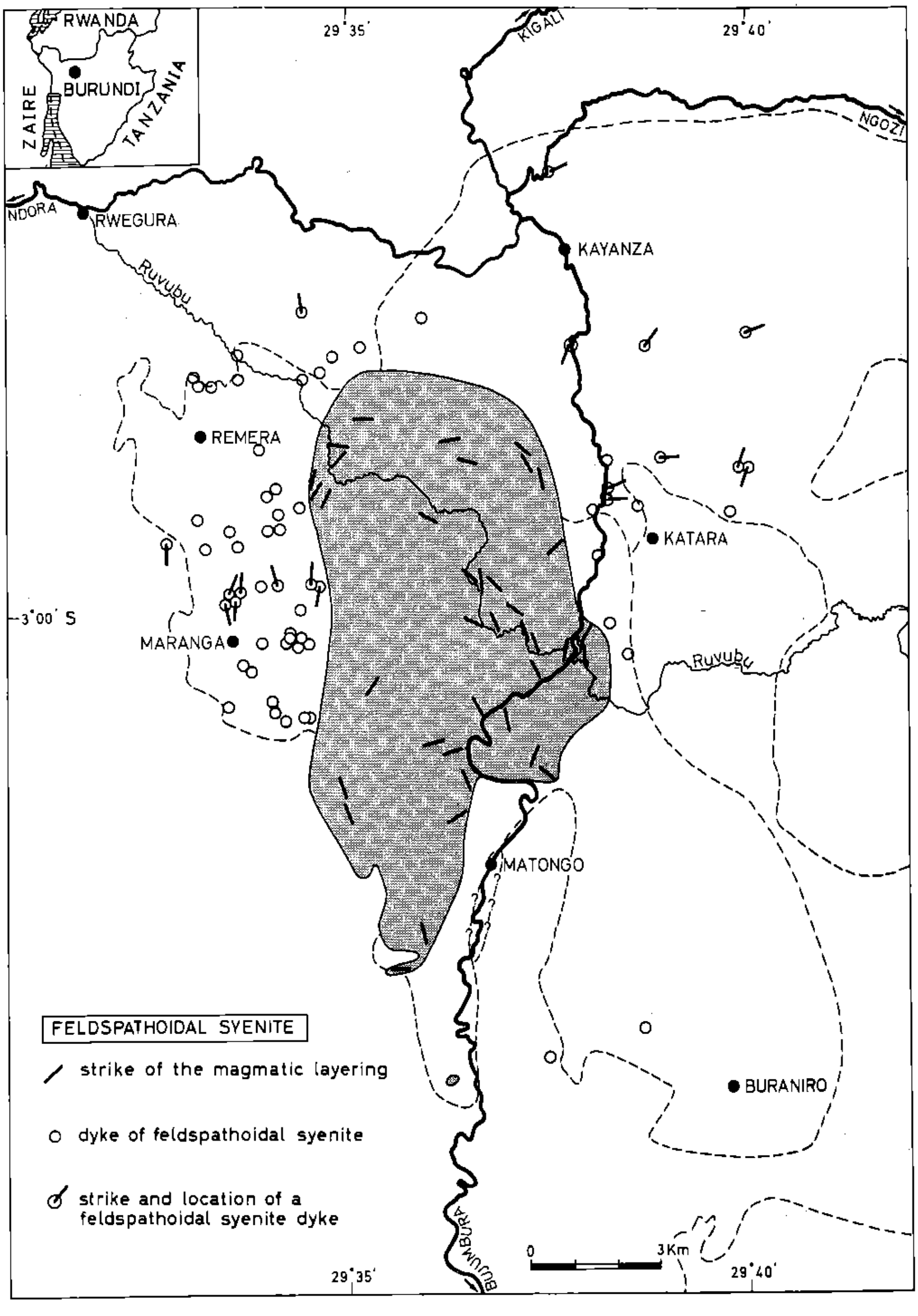

Fig. 3.- Distribution of the foïdal syenites in the alkaline complex.

gregation zones are observed. Grey varieties of quartz syenites seem preferably associated with the gabbro-diorite areas. The essential constituents of the quartz syenites are alkali-feldspars, quartz, biotite, some plagioclase and alkali-rich pyroxenes and/or amphiboles. Both the quartz and the plagioclase contents of the rocks are extremely variable. In the vicinity of Matongo the quartz syenites are strongly kaolinized.

As it is not possible to distinguish between gabbros and diorites (anorthite content close to An 50) in the field they were mapped as a single unit. Both rock types are usually medium to coarse-grained and dark coloured. Four mafic minerals are observed in the gabbros and diorites : olivine, augitic clinopyroxene, hornblende and biotite. It is not exceptional to find these four minerals in a single rock sample. In strongly metasomatised gabbros and diorites the primary pyroxenes and amphiboles are partially or entirely converted into green alkali-rich minerals of the pyroxene and/or amphibole group.

Dykes associated with the outer unit are rare and not represented on the map. Most common are dykes of quartz syenite, either porphyritic and rather dark-coloured or aplitic and light-coloured. Pegmatites have not been observed.

Screens of Burundian country rock and angular xenoliths are quite common mainly on the outer border of this unit.

The foid-bearing syenites (fig. 3)

Foid-bearing syenites and subordinate amounts of feldspathoidal monzonites constitute the core of the complex. Trachytoid-textured foid-bearing syenites are less common than granular types. Grain-size variations are omnipresent. Nepheline, which in some localities is replaced by sericite and other secondary minerals, is the most common feldspathoid. Sodalite and cancrinite are less widely distributed. Among the alkali-feldspars microcline, microcline-microperthite, orthoclase-microperthite and albite were observed. The feldspathoidal syenites and monzonites are characterized by a great diversity of mafic constituents, the most common ones being biotite, aegyrine-augite, a green alkali-rich amphibole, two types of garnet, opaque minerals (o.a. specular hematite and pyrite), sphene, calcite, muscovite, apatite, zircon and fluorite. With increasing mafic mineral content the feldspathoidal syenites grade into malignites.

As the foid-bearing syenites and monzonites show a wide range of textures and compositions, even over very short distances, detailed geological mapping proved to be impossible. Four textural rock types however are predominant and can easily be recognized in the field (Tack & De Paepe, 1981).

a. The aplitic type

Numerous dykes of aplitic foid-bearing syenite cut the outer unit and the Burundian rocks (fig. 3). They are particularly common in the northern and north-western part of the complex. One of them is located more than 13 km to the NW of the core of the URAPC (out of the limit of the map). Large areas of the core of the URPAC are constituted by aplitic-textured rocks. As they are resistant to tropical weathering, this has lead in the past to overestimate the regional extent of these aplitic rocks and, consequently, of the foidal-syenite body. It is likely that the grey aphanitic rock described by Thoreau (1932) corresponds to an aplitic-textured nepheline syenite.

b. The medium to coarse-grained type

Some rocks of the medium to coarse-grained type are porphyritic or pegmatitic. Others are characterized by a subparallel arrangement of their constituent minerals. Pegmatite dykes are rare and were only observed in the foidal-syenite core. Pegmatitic segregations of foidal syenite are however very abundant all over the massif. The following minerals have been recognized in the rocks of pegmatitic type : white alkali-feldspars, dark green to greyish black nepheline, blue sodalite, brownish, brown red or yellow cancrinite, a green fibrous clinopyroxene, a black prismatic amphibole, biotite, garnet, specular, hematite pyrite, chalcopyrite and violet fluorite.

c. The brecciated type

The brecciated structure of these rocks results from the abundance of angular to subrounded rock fragments of different size and composition (fig. 4). Some are gabbroic or dioritic; such fragments certainly originate from the outer unit as they are common near the contact with the latter. Other fragments belong to a suite of nepheline-rich, feldspar-free alkaline plutonic rocks. In some magmatic breccias we found light-coloured xenoliths.

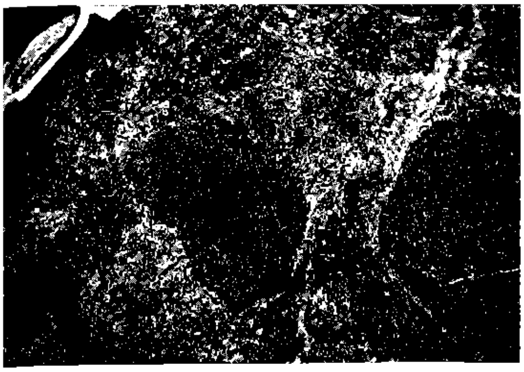

Fig. 4.- 800 m. south-west of road intersection of Kiziba (LT 472).

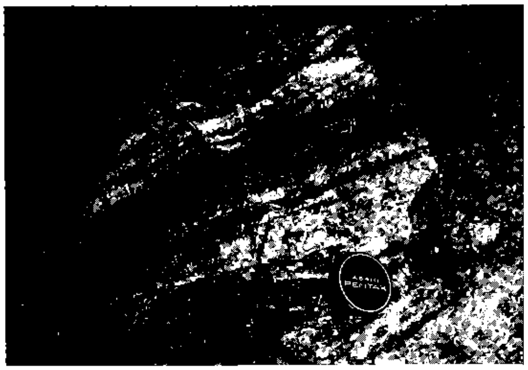

Fig. 5.- 2 km. west of Mubuga mission along Rushishikira river (LT 363-365).

Fig. 6.- 2,2 km. north of tea centre of Campazi (LT 510).

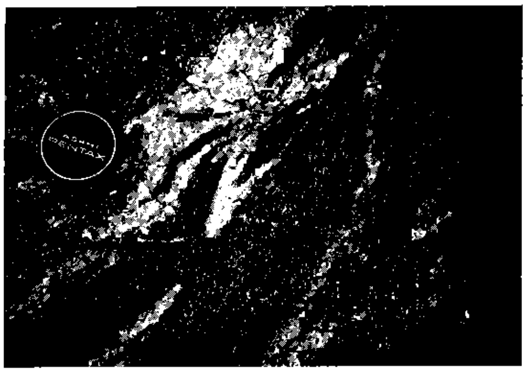

Fig. 7.- 2 km. west of Mubuga mission along Rushishikira river (LT 363-365).

d. The banded or layered type

The banding or layering is the most striking feature of these rocks. It is not of tectonic origin but reflects a purely magmatic phenomenon and results from variations in grain size, texture or mineralogy of adjacent bands or streaks (fig. 5). The banding is observable as well on a large scale (outcrop) as on a medium scale (hand specimen) or small scale (thin section). In fact the banded rock type represents a roughly concordant alternation of the previously described aplitic and medium to coarse-grained feldspathoidal syenites on a macroscopical or microscopical scale. Banded rock types may gradually evolve into rocks which include clear-cut or diffuse schlieren (fig. 6) or dark spotted textures, reminiscent in some respects of rocks belonging to the brecciated type (fig. 7).

Magmatic layering is common all over the central foidal-syenite core. The banding is roughly parallel to the margins of the intrusion (fig. 3) with steep (more than 60°) and usually subvertical dips.

According to Poldervaart & Taubenek (1960) magmatic layering or banding may result from two distinct processes : (1) a magmatic fractionation followed by gravity accumulation of crystals at either the base or the top of an intrusion, or (2) flow or shear differentiation during emplacement near the margins of the intrusion due to deformation or movement of a crystal mush, generally inducing sedimentary type structures such as truncated layers, slump folds, graded bedding, trough banding, etc.

A recent study of the Shira ring-complex in Northern Nigeria (Bennett, 1981) has shown, however, that other mechanisms may be involved.

According to Bennett (*op. cit.*) the cyclic layering which occurs in the Birji granite of the Shira complex is induced by an oscillatory process of nucleation and crystal growth of alternatively arfvedsonite or quartz in interstices, which takes place after the crystallization of a framework of alkali-feldspar. The build-up of such a framework is governed by cooling from the steeply inclined walls of the intrusion.

It is likely that this model is also applicable to the Upper Ruvubu feldspathoid-bearing syenites as nowhere «gravity» or «sedimentary» structures have been observed in the field. On the contrary, the layering is rhythmic, often repeated, near-vertical and generally parallel to the walls of the intrusion. Moreover rocks that look quite different either on macroscopic or on microscopic scale have similar chemical compositions. There is also no evidence for crushing of the minerals nor for induced foliation suggesting a tectonic process, a shearing or a forceful intrusion. Thus, relative rates of nucleation and chemical diffusion within the interstitial liquid during cooling under stable gravitational conditions, especially in the case of supercooled magmas with low viscosity and high volatile content like most alkaline magmas, may be considered to be the dominant operative process for the production of layering in plutonic massifs such as the core of the URAPC.

This in situ mechanism is described by Bennett (1981) as «*constitutional supercooling :* when crystal 'A' grows, it accepts certain components from the liquid and rejects others. If the rate of crystal growth exceeds the rate of diffusion of the rejected components, a boundary layer enriched in these components will form. These rejected components will modify (lower) the liquid temperature and hence the term «constitutional supercooling» is given. A point will ultimately be reached when the components rejected by crystal 'A' will supersaturate the boundary layer and crystal 'B' will crystallise instead. The major control for this process is believed to be the temperature gradient».

The carbonatites

The carbonatitic body is only known by drilling in the subsoil of Matongo at a minimum depth of 40 m. The carbonatite of Matongo was not studied by the authors of this paper but has been the subject of several sophisticated research programs, some of them still in progress. They include mineral exploration and evaluation programs commissioned by the Burundese Government (UNDP project; Matongo phosphate project of the British Sulphur Corporation Ltd.) and a doctorate's thesis on their petrology and geochemistry (Midende, 1984). Using their data the approximate extent of the carbonatite body is indicated on our maps.

The carbonatite of Matongo forms a dyke-like elongated (about 2750 m long and 250 m wide) intrusion and probably represents the youngest event of the URAPC. The presumable boundary of the body was deduced from geophysical prospection and drillings carried out in the area. The carbonatites of Matongo include silico-carbonatites, nearly pure sövites and sövites with biotite, aegyrine and/or alkali-rich amphiboles. Some carbonatites are ferriferous or dolomitic. Several boreholes have shown that economically important phosphate (usually apatite) concentrations occur near the top of the body. The carbonatites are characterized by a great textural and mineralogical heterogeneity. Magmatic layering with subvertical dips and magmatic breccias have been observed.

As far as we know the drilling data did not allow the age and spatial relationships between the feldspathoidal syenites and the carbonatites to be established. In this context it is worth noting that we found in one locality, situated in the northward prolongation of the axis of the carbonatite body, a magmatic breccia which is traversed by carbonatitic veinlets (fig. 1). These veinlets consist of calcite, apatite and biotite with subordinate amounts of pyrite, specular hematite and other opaque minerals. Flow textures on microscopic scale suggest that the carbonatitic material was injected in the foid-bearing breccia. Semi-quantitative Sr determinations carried out on the soluble fraction of the carbonatite veinlets yielded concentrations of more than 3500 ppm and these data are in agreement with the Sr contents recorded in the Matongo carbonatites (Midende, pers. comm.). Similar Sr concentrations characterize the carbonatites of the Lueshe complex, Zaïre (Maravic & Morteani, 1980) and of the Sangu-Ikola complex, Tanzania (Coetzee, 1963), the latter presenting striking similarities with the Matongo-carbonatite. The related features support the idea that the intrusion of the carbonatites of the URAPC represents a magmatic event which is posterior to the emplacement of the foid-bearing syenites. The same conclusions were obtained in the Lueshe complex (Meyer, 1958) and in the Nachendezwaya Hill massif (Geological map of Tanzania, Quarter degree Sheet 258 and 258S, Itumba, 1966). According to Midende & Demaiffe (1983) the carbonatites are also younger than the foidal syenites.

EMPLACEMENT CONDITIONS AND STRUCTURAL EVOLUTION OF THE URAPC

The outer unit is discordant with respect to the stratification of the Burundian formations and the S1-foliation characterizing them. Near its northernmost margin the gabbro-diorites intruded Burundian rocks metamorphosed in the pyroxene-hornfels facies. This contact aureole is not indicated on the different maps (fig. 1-3). In other places chilled margins with microporphyritic textures have been observed. The outer unit was intruded at the limit of the antiform and synform structures of Kibaran age. The presence of high-temperature quartz crystals in the granites I and II suggests that these granites have to be considered as high-level intrusions.

As shown on figure 2, the Burundian rocks of the Upper Ruvubu region are characterized by a prominent non-penetrative N-S to NNW or NNE trending S2-cleavage and/or schistosity. The phyllites e.g. were particularly susceptible to the deformation forces that induced this foliation and, therefore, they often show a very well-developed strain-slip cleavage or crenulation cleavage. A non-penetrative foliation is however also observed in the oldest unit of the URAPC. The regional distribution of the foliated rocks in the outer unit is far from being uniform. The field observations indicate, indeed, that the rocks belonging to the western zone of the outer unit are usually more affected than those exposed east of the foidal-syenite core. Many rocks of the outer unit also display crushing of their constituent minerals, cataclastic deformation or augen structures. These features are developed in some quartz syenites and in the granites I or III. In the most extreme cases the deformation gave rise to the development of shear zones with a N-S to NNW or NNE orientation. As the strike of the non-penetrative foliation of the older unit of the URAPC is parallel to that of the S2-cleavage of the Burundian formations it is reasonable to consider that both resulted from a single N-S tectonic episode that succeeded the emplacement of the outer unit.

A structural survey of the foid-bearing syenitic core of the URAPC indicates that the intrusion of these rocks was late-tectonic with respect to the N-S episode that induced the S2 deformation in the area. Indeed, strongly crushed or foliated rocks of the outer unit are often concomitantly observed with undeformed foid-bearing syenites. Moreover, foliated foidal syenites or crushed minerals occur only exceptionally. As mentioned above the shape of the undersaturated core of the URAPC is elongate and the great axis of the ellipse is N-S oriented. Furthermore, dykes of foid-bearing syenite are very abundant whereas only a few dykes related to the outer unit have been observed. The numerous dykes of foid-bearing syenite that cut not only the older rocks of the URAPC but also the Burundian country rocks are not arranged in a radial way with respect to the central foidal syenites but they usually have a N-S, NNW or NNE trending strike and near-vertical dips (fig. 3). Some of them also have strikes that belong to a conjugate joint system. All these features indicate that in the Upper Ruvubu area the S2 tectonic episode gave rise to the formation of locally developed and roughly N-S trending zones of weakness in the earth's crust that substantially facilitated the subsequent intrusion of the foidal syenites. Both the shape of the intrusive body and the steep dip of the concentric magmatic layering suggest a mechanism of diapiric intrusion. The subvertical, upwards moving and rather fast intrusion of the core may be held responsible for the fact that fenitization in the adjacent rocks is usually poor or even absent.

The carbonatites that underlie the quartz syenites near the southern boundary of the URAPC form apparently a NNE trending dyke-like intrusion with a subvertical dipping magmatic layering. The emplacement of this elongated intrusive body was undoubtedly also structurally controlled by preexisting fractures and faults in the area related to the N-S tectonic episode.

There is also evidence that zones of weakness or faults were reactivated in the later periods. This is indicated by the presence of thermal springs (Mvumvu thermal waters, after Deelstra *et al.*, 1972) and the occurrence of several tectonic breccias in the carbonatite.

As stated above the plutonic rocks adjacent to the carbonatites are strongly kaolinized. Although this feature was not studied in detail it is believed that it represents the supergene weathering zone of albitites, which derived from the fenitization of the quartz syenites that cap the carbonatitic intrusion. The metasomatism was not necessarely a purely sodic one as proposed by Coetzee (1963) for the Sangu-Ikola carbonatites in Tanzania. K- or combined K-Na-metasomatism aureoles around carbonatites are well known (Mariano, pers. comm.) and would also produce kaolinites under tropical weathering conditions.

AGE AND ISOTOPIC GEOCHEMISTRY

Analytical methods

The isotopic compositions of Sr, which was separated on ion exchange resin, have been measured on double Re filaments in the Varian Mat 260 and TH5 mass spectrometers of the Belgian Centre for Geochronology (MRAC-ULB). The NBS 987 standard $^{87}Sr/^{86}Sr$ value is 0.710235 ± 0.000026 (2σ m) normalized to $^{86}Sr/^{88}Sr = 0.1194$. The ages were calculated according to Williamson (1968) and all the errors are quoted at 2σ level. The $\lambda\,^{87}Rb$ is $1.42\ 10^{-11} y^{-1}$. Sr and Rb concentrations were measured by X-ray fluorescence at MRAC, Tervuren.

Pb and U separations on two different zircon fractions have been made using the method described by Krogh (1973), the silica gel technique on a Re filament being used for the isotopic determinations.

Nd was separated from other REE using HDEHP [di(2 ethylhexyl) orthophosphoric acid] on teflon powder columns as described by Richard *et al.* (1976). These columns were calibrated with ^{139}Ce (T = 140d, γ = 0.275 MeV). Nd (± 1 μg) loaded on the side filament of a double Re filament is run as Nd^+ and the $^{144}Nd^+$ ion beam of 0.4 to 2.10^{-11}A lasts several hours. In each run four isotopes (146, 143, 144 and 145) are measured in sequence, the zero line being taken at mass 147.5. The mean $^{145}Nd/^{144}Nd$ value obtained on different samples is 0.34837 ± 3 (2σ m) normalized with $^{146}Nd/^{144}Nd = 0.7219$ (Weis & Deutsch, 1984). Sm and Nd concentrations were determined by instrumental neutron activation analysis by Hertogen (KUL) with a precision of ± 3% (1σ) on Sm/Nd ratios (Hertogen & Gijbels, 1971). The precision of the INAA determinations was checked by comparison with isotope dilution.

Geochronology

In order to date the N-S tectonic phase and the emplacement of both the outer unit and the foidal syenites preliminary zircon U-Pb determinations on the foidal syenites and Rb-Sr measurements on the two mapped units have been carried out.

The analysed zircons from a foidal syenite are clear, without inclusions and not rounded. Their magmatic morphology, the near concordance of the U-Pb ages, the much older age of the country rocks (Kibaran, 1350-1180 Ma) (Klerkx *et al.*, 1984) and the weak upper crust contamination (Sr and Nd initial ratios, see below) rule out any inheritance in these zircons. The upper intercept on Concordia of two slightly discordant zircon fractions gives a value of 739 ± 7 Ma (lower intercept near zero, table 1, fig. 8).

On the other hand, a Rb-Sr age of 699 ± 13 Ma (0.70364 ± 0.00014, MSWD = 5.2 for 9 WR, table 2, fig. 9) was obtained for the foidal syenites. This value, which is lower than the zircon age, and the poor quality of the isochron (MSWD = 5.2) are in favour of an incomplete rehomogenization at about 700 Ma. Moreover the granites and the quartz syenites of the outer unit give a similar age with a higher initial ratio : 707 ± 17 Ma, 0.7077 ± 0.0088, MSWD = 1.6. This age is based only on selected samples (7WR) (table 2, fig. 10). The samples not included in the isochron of figure 10 correspond either to rocks with high Rb-Sr ratios and low Sr concentrations and which lost radiogenic Sr during subsequent events or to samples with low Rb-Sr ratios whose positions on the graph are more likely interpreted by an incomplete rehomogenization during the 700 Ma event as is the case for the foidal syenites. In addition to the URAPC rehomogenization a similar event has been dated at 697 ± 18 Ma on Kibaran granites in Western Burundi (Liégeois *et al.*, 1982; Theunissen & Klerkx, 1983). In pre-Kibaran gneisses of Rwanda Gérards & Ledent (1976) have observed the influence of a «Lufilian tectonic phase» (676 ± 70 Ma, Rb-Sr rehomogenization; 673 Ma, lower intercept in the Concordia diagram).

Since the N-S tectonic phase which affected the outer unit was anterior to the foidal-syenite emplacement, its age must be greater than 739 Ma. Thus

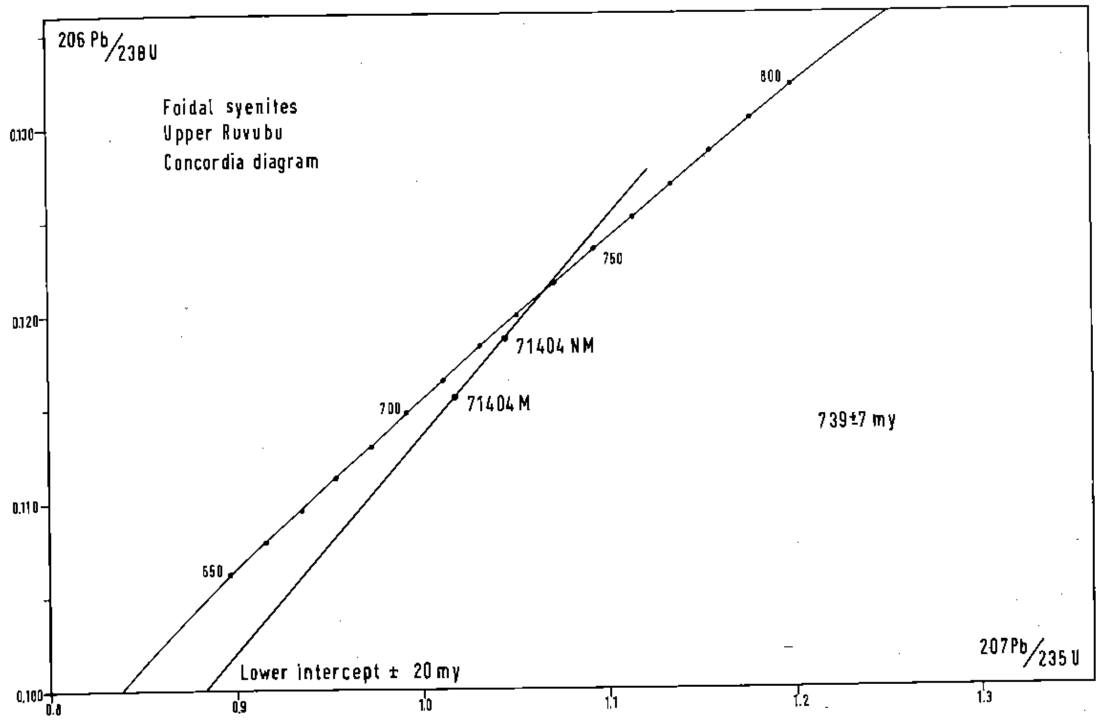

Fig. 8.- Concordia diagram of the foidal syenites.

Table 1. - U-Pb data on zircons from the URAPC (foidal syenites)

Sample	Fraction	U ppm	Pb tot ppm	Pb rad ppm	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
71404	M1.5A,2°	506	70.3	68.9	27.55	0.06904	0.31509
71404	NM1.5A,1°	318	46.0	41.7	586.5	0.08850	0.27856

Apparent ages in millions years

Fraction	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$
M1.5A,2°	736 ± 10	705 ± 7	713 ± 7
NM1.5A,1°	738 ± 7	723 ± 7	727 ± 7

Correction Pb : $^{206}Pb/^{204}Pb = 18.6$; $^{207}Pb/^{204}Pb = 15.7$; $^{208}Pb/^{204}Pb = 38.9$; $\lambda\,^{238}U = 1.55125\ 10^{-10}y^{-1}$; $\lambda\,^{235}U = 9.8485\ 10^{-10}y^{-1}$; $^{238}U/^{235}U = 137.88$.

Table 2. - Rb-Sr data of the URAPC

Sample	Rock type	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ (±2σm)	$^{87}Rb/^{86}Sr$ (± 2%)
LT 26		24	950	0.7046 ± 0.0006°	0.074
LT 111	gabbros-	42	958	0.7044 ± 0.0002°	0.126
LT 347	diorites	84	611	0.70801 ± 0.00007	0.398
46 944*		36	1277	0.7049 ± 0.0004°	0.082
46 956*		39	899	0.7056 ± 0.0003°	0.126
LT 95		240	46	0.8643 ± 0.0006°	15.3
LT 485	quartz	115	56	0.7594 ± 0.0007°	6.00
LT 566	syenites	147	243	0.72530 ± 0.00003	1.75
46 957*		206	141	0.7405 ± 0.0007°	4.24
LT 96		289	31	0.9815 ± 0.0007°	27.3
LT 928		299	30	0.95923 ± 0.00007	30.0
LT 929		304	33	0.9464 ± 0.0003°	27.5
LT 956		242	32	0.86818 ± 0.00004	22.2
LT 977		324	17 φ	1.18231 ± 0.00013	57.8
LT 996	granites	151	109	0.75030 ± 0.00009	4.03
LT 1011		259	88	0.79298 ± 0.00005	8.59
LT 1013		206	133	0.74436 ± 0.00011	4.50
LT 1033		208	94	0.76578 ± 0.00006	6.44
LT 1034		229	102	0.77253 ± 0.00009	6.54
LT 1099		118	113	0.73785 ± 0.00005	3.03
LT 36		135	63	0.7673 ± 0.0003°	6.25
LT 46		168	56	0.7918 ± 0.0003°	8.72
LT 253		134	1476	0.70624 ± 0.00003	0.263
LT 259		187	212	0.72697 ± 0.00012	2.56
LT 512	foidal	181	75	0.77094 ± 0.00004	7.03
LT 595	syenites	172	133	0.7427 ± 0.0006°	3.76
LT 596		120	262	0.7218 ± 0.0006°	1.33
LT 604		160	579	0.71174 ± 0.00004	0.800
LT 623		130	112	0.7381 ± 0.0006°	3.37
71 404*		218	482	0.7186 ± 0.0006°	1.31
LT 105	(dyke)	227	17	1.0639 ± 0.0007°	40.0

Performed on VARIAN MAT 260 and VARIAN TH5 (°) mass spectrometre of the Belgian Centre for Geochronology.
The $^{87}Sr/^{86}Sr$ ratios are normalized with $^{86}Sr/^{88}Sr = 0.1194$.
$\lambda^{87}Rb = 1.42\ 10^{-11}y^{-1}$.
(+) measured by X-ray fluòrescence by C. Léger of MRAC.
(φ) measured by isotopic dilution.
(*) measurements from Cahen *et al.* (1979).

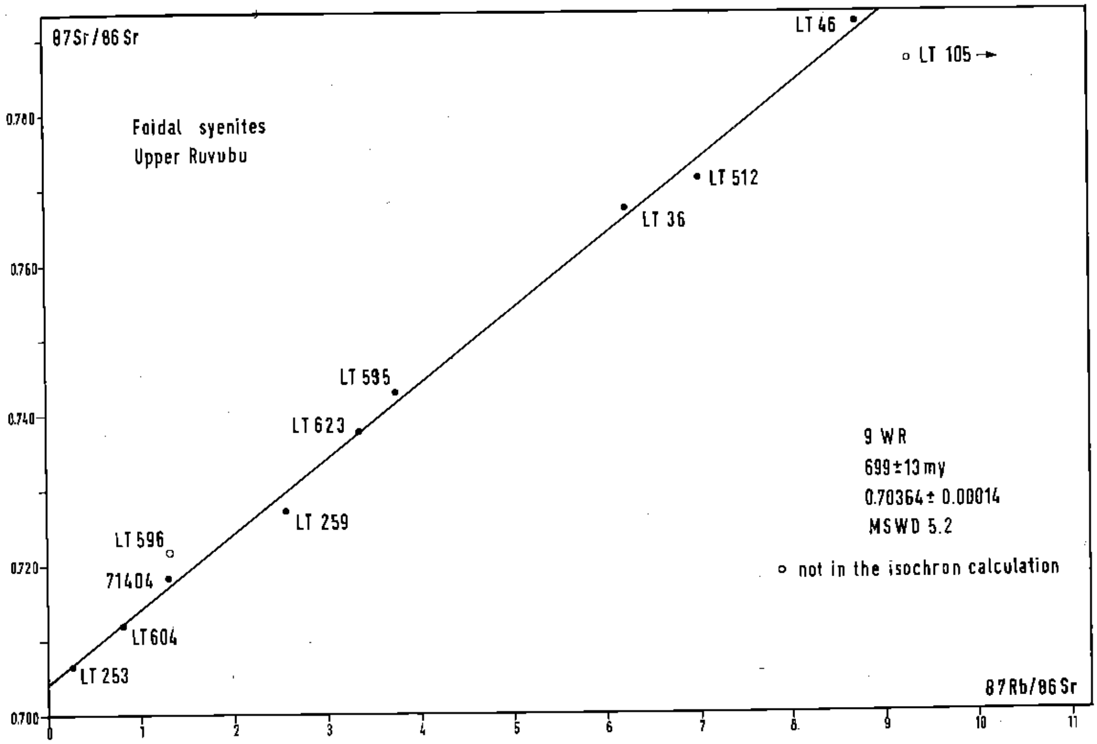

Fig. 9.- Isochron of the foidal syenites.

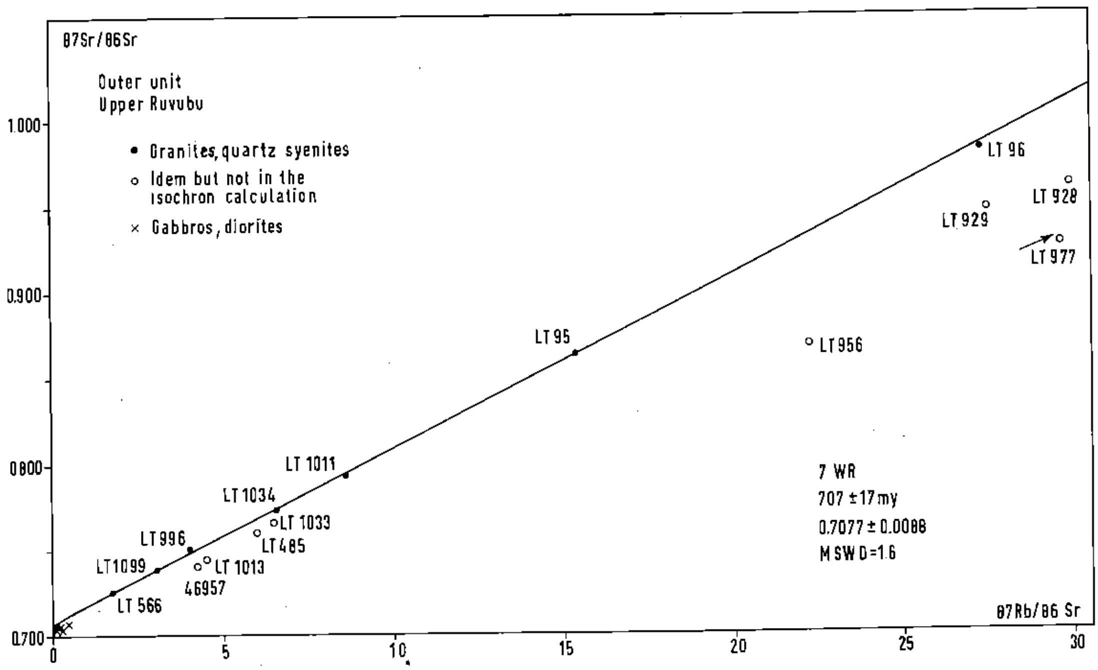

Fig. 10.- Isochron of the outer unit.

the younger event (± 700 Ma) which rehomogenized the Rb-Sr system of the URAPC and of the Kibaran granitoids must be associated with a later manifestation of the N-S phase. This manifestation, characterized mainly by a thermal effect, is called NS2 episode in opposition to the earlier tectonic episode NS1. It is possible that during the NS2 episode reactivation occurred along the shear zones originated during the NS1 episode. The relatively large number of samples of the outer unit which lies out of the isochron as compared to the foidal syenites can result from an incomplete rehomogenization of the older unit during the NS1 episode which did not affect the younger one. Indeed, this NS1 event is characterized in Western Burundi by a spatial variation of its intensity (Theunissen & Klerkx, 1983) and thus produced rehomogenization at different degrees depending on the mineralogical composition of the rocks.

The gabbros and diorites form a homogeneous group lying below the granite-quartz syenite isochron. The lack of rehomogenization in this group as compared to the existing rehomogenization of the granites and the quartz syenites allows an estimation of 0.7030 for the $^{87}Sr/^{86}Sr$ initial ratio (Ro) of these basic rocks. This value takes into account a small correction for the radiogenic ^{87}Sr over a period of 740 Ma due to the low Rb/Sr ratios of the gabbros and the diorites.

The value is similar to the original Ro of the foidal syenites (0.7025, recalculated taking into account the zircon age) and of the Matongo carbonatites (0.7030) (Midende & Demaiffe, 1983). If we accept a cogenetic origin for the rocks of the outer unit, based essentially on the continuity between the different petrographical types and their identical εNd, a model-age can be evaluated assuming a mean $^{87}Rb/^{86}Sr$ value for the granite -quartz syenite group. This mean value, on the one hand, may be overestimated by averaging all the isotopically analysed samples as the isochron method requires the largest possible scatter of the Rb/Sr ratios and, on the other hand may be underestimated by considering only the sample group with a $^{87}Rb/^{86}Sr$ ratio below 10. With these two extreme values, the age brackets calculated (729 Ma - 773 Ma) indicate that the emplacement of the outer unit took place between 773 and 739 Ma, probably a short time before the emplacement of the foidal syenites.

A model for the emplacement sequence of the URAPC is presented in table 3. The emplacement ages around 740 Ma prove that the URAPC belongs to the Pan-African. In this area the N-S phase that induced the S2-foliation represents also an early

Table 3. - Emplacement sequence of the URAPC

- 699 ± 13 Ma	Rb-Sr on WR of foidal syenites; Ro= 0.7036	N-S2 EPISODE : incomplete isotopic rehomogenization of Sr of the units of the URAPC and of the Kibaran country rocks as a result of a regionally developed THERMAL PEAK related to N-S phase; possible reactivation along N-S1 zones.
- 707 ± 17 Ma	Rb-Sr on WR of outer unit; Ro = 0.7077	
- 739 ± 7 Ma	Zircon age on foidal syenites	N-S structurally controlled diapiric EMPLACEMENT OF FOIDAL SYENITES, followed by carbonatites.
		N-S1 FAULTING TECTONIC EPISODE : locally developed shear zones, non-penetrative S2-foliation and cataclastic deformation of outer unit and of Kibaran country rocks; possible incomplete isotopic rehomogenization of Sr.
		Atectonic high-level EMPLACEMENT OF OUTER UNIT with model age between 773-739 Ma (recalculated with Ro = 0.7030; see text).

N.B. N-S1 and N-S2 are different episodes of the same N-S phase.

Pan-African event. In a more general way such a N-S deformation has been evidenced throughout Burundi by Theunissen & Klerkx (1983). Our results, finally, illustrate the complexity of this regionally developed N-S phase. Indeed a distinction can be made between an earlier «tectonic» episode, with dominant deformational aspects of varying intensity and effects (locally developed folding and shear, non-penetrative schistosity, faulting), and a slightly later «thermal» episode expressed through the Rb-Sr rejuvenation ages resulting from the closure of the isotopic system.

Origin of the parental magma

The Nd isotopes measured on four samples (1 gabbro, 1 quartz syenite, 1 granite and 1 foidal syenite) indicate slightly positive $\varepsilon^{BE}_{740\ Ma}$ values : foidal syenite : + 1.7 ± 1; mean value of the outer unit : + 2.3 ± 1.5 (table 4). A common source for the different rock types of the URAPC is thus likely. These calculated initial Nd values, together with the low Sr initial ratios (0.7025 - 0.7030), point to an essentially mantellic source for these rocks excluding a participation of the upper crust. As the URAPC Nd and Sr ratios are in the «mantle array» close to the bulk earth values 740 Ma ago, we can consider the URAPC source comparable to that of the recent ocean island basalts (O'Nions *et al.*, 1977). This implies a roughly primitive deep mantle (probably asthenospheric mantle) producing alkaline magmas since the Pan-African. The idea that alkaline complexes can infer the mantle composition in the past is then confirmed as pointed out by Weis *et al.* (in press) who draw similar conclusions for the Permian undersaturated complex of Tadhak, Mali.

It must be pointed out that there are fundamental differences between the Upper Ruvubu granites and quartz syenites and the calc-alkaline granitoids of the Kibaran. The latter are not only directly related to a tectonic phase which constrains their emplacement (Klerkx *et al.*, 1984) but have also S-type characteristics (Liégeois *et al.*, 1982). The anorogenic tin granites (980 Ma) are also very different : they have very high Sr initial ratios (up to 0.770, Cahen & Ledent, 1979; Lavreau & Liégeois, 1982) and distinct petrographical characteristics. The URAPC represents therefore a new type of magmatism heralding a new stage in the geodynamical history of the region.

IMPLICATIONS FOR THE REGIONAL GEOLOGY OF THE WESTERN RIFT

Although the URAPC is composed of a unique association of various plutonic rocks it is not an isolated feature in the Western Rift area (fig. 11). A

Table 4. - Sm-Nd data of the URAPC

Sample	Rock type	Sm^{+} ppm (± 2%)	Nd^{+} ppm (± 4%)	$^{143}Nd/^{144}Nd$ $(\pm 2\sigma_m)^{\circ}$	$^{147}Sm/^{144}Nd$	$(^{143}Nd/^{144}Nd)_{740}$	ε^{BE*}_{740}
71 404	Foidal syenite	6.9	50	0.512176 ± 25	0.08354	0.511771	+ 1.7
LT 347	Gabbro	8.1	53	0.512320 ± 26	0.09273	0.511870	+ 3.6
LT 996	Granite	10.5	66	0.512284 ± 27	0.09547	0.511821	+ 2.6
LT 566	Quartz syenite	22.2	135	0.512206 ± 22	0.09938	0.511724	+ 0.7

(+) measured by neutron activation by J. Hertogen (KUL).
(°) between run precision 5.10^{-5}
Johnson Matthey NdO standard : $^{143}Nd/^{144}Nd$ = 0.51198 ± 5
BCR 1 : $^{143}Nd/^{144}Nd$ = 0.51267 ± 3
normalized to $^{146}Nd/^{144}Nd$ = 0.7219
(*) Bulk earth values (Jacobsen and Wasserburg, 1980)
$(^{143}Nd/^{144}Nd)_0 = 0.51264$; $(^{147}Sm/^{144}Nd)_0 = 0.1966$; $\lambda Sm = 6.54\ 10^{-12} y^{-1}$
$\varepsilon BE = [(^{143}Nd/^{144}Nd)_t / (^{143}Nd/^{144}Nd)\ BE) - 1] 10^4$; $2\sigma\ \varepsilon_t = \pm 1$.

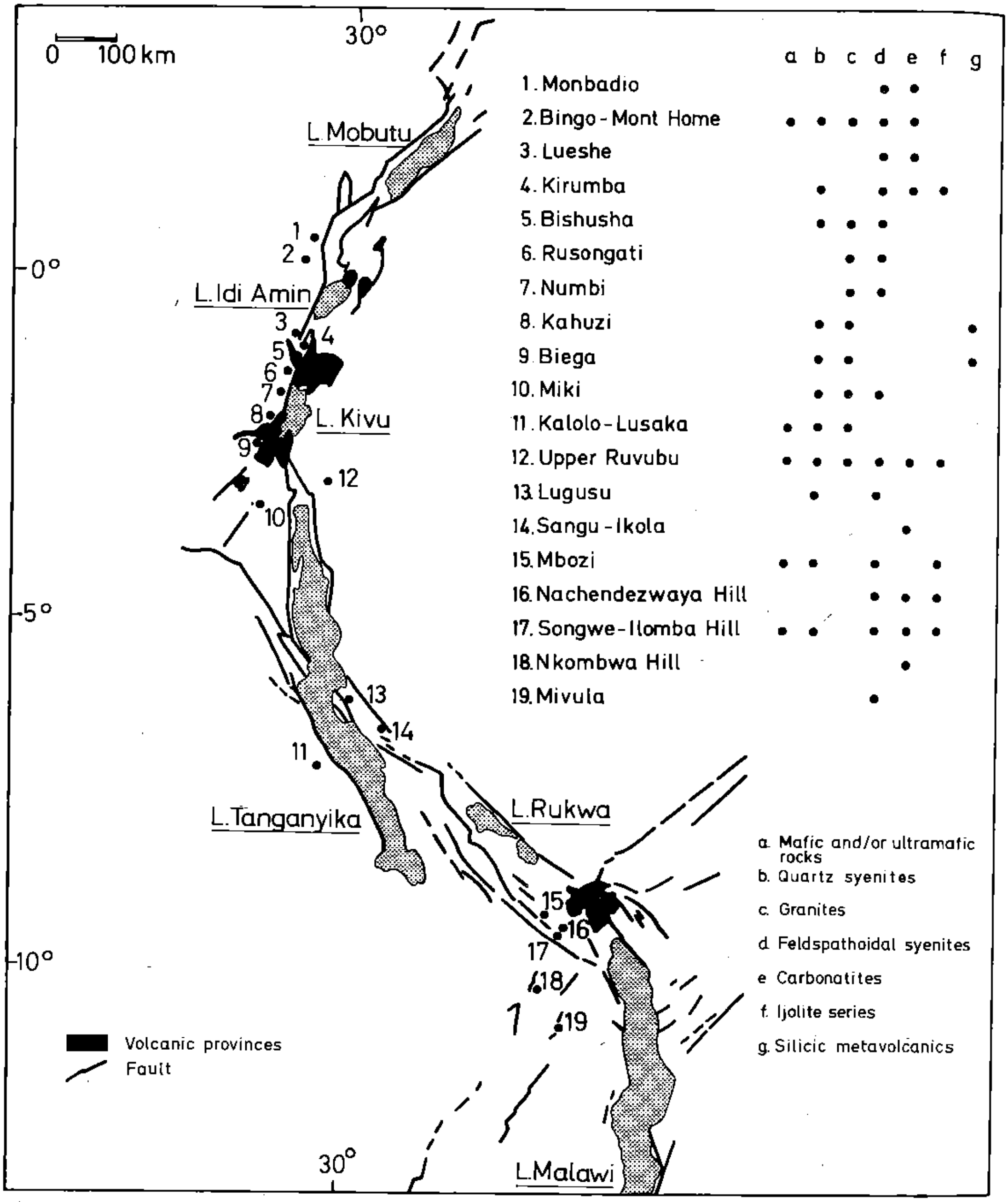

Fig. 11.- Spatial distribution and rock types of 19 alkaline massifs located along the Western Rift.

Table 5. - List of 19 alkaline massifs located along the Western Rift with available radiometric data

Complexes	References	Radiometric ages	Nature and number of dated samples	References
1. Monbadio (Zaïre)	1			
2. Bingo-Mont Home (Zaïre)	1,2,3			
3. Lueshe (Zaïre)	1,3,4,5,6,7	516 ± 26 (K-Ar)	1Bi	8
4. Kirumba (Zaïre)	1,3,9,10,11	259 ± 13 (K-Ar)	1WR	8
		501 ± 72 (Rb-Sr)	1WR+1Pl+1Mi	12
		± 580 (Rb-Sr)	1Bi	12
		688 ± 33* (Rb-Sr)	1Bi	13
5. Bishusha (Zaïre)	3,9			
6. Rusongati (Zaïre)	3,9			
7. Numbi (Zaïre)	1,3,9,14	± 520 (Rb-Sr)	1Bi	12
8. Kahuzi (Zaïre)	1,3,15,16,17, 18,19,20	493 ± 12 to 452 ± 11 (K-Ar)	2WR+2Bi	21
		134 ± 7 (K-Ar)	1WR	8
		55 ± 3 (K-Ar)	1WR	8
		728 ± 25 (Rb-Sr)	6WR	22
9. Biega (Zaïre)	1,3,15,16,20,23	555 ± 13 to 442 ± 11 (K-Ar)	2WR+2Bi	21
10. Miki (Zaïre)	1,3,24			
11. Kalolo-Lusaka (Zaïre)	1,3,25	781 ± 83 * (Rb-Sr)	3WR	26
		604 ± 50* (Rb-Sr)	2WR+2F+1Hb	26
		1106 ± 27 (K-Ar)	1Hb	26
		877 ± 23 (K-Ar)	1Hb	26
12. Upper Ruvubu (Burundi)	27,28, this paper	774 ± 88 (Rb-Sr)	3WR	12
		699 ± 13 (Rb-Sr)	9WR	this paper
		707 ± 17 (Rb-Sr)	7WR	this paper
		739 ± 7 (U-Pb)	2Zr	this paper
13. Lugusu (Tanzania)	29			
14. Sangu-Ikola (Tanzania)	29,30,31			
15. Mbozi (Tanzania)	32,33,34	745 ± 25 (K-Ar)	1Bi	13
		743 ± 30 (K-Ar)	1Bi	33
16. Nachendezwaya Hill (Tanzania)	35,36,37			
17. Songwe-Ilomba Hill (Malawi)	32,37	685 ± 62 (Rb-Sr)	3WR	38
		655 (Pb-α)	Zr	38
		500 (K-Ar)	1Bi	39
18. Nkombwa Hill (Zambia)	39	680 ± 25 (K-Ar)	1Ph	13,39
19. Mivula (Zambia)	39	550 ± 20 (K-Ar)	1Bi	13,39

* recalculated with $\lambda^{87}Rb = 1.42.10^{-11}$ y $^{-1}$ and errors at 2σ level.
WR = whole rock; Bi = biotite; Pl = plagioclase; Mi = microcline; F = feldspar; Hb = hornblende; Zr = zircon; Ph = phlogopite.

References : (1) Carte des gîtes minéraux du Zaïre 1974; (2) Gosseye & Czican 1960; (3) Lepersonne 1974; (4) de Béthune 1958; (5) Maravic & Morteani 1980; (6) Meyer 1958; (7) Meyer & de Béthune 1960; (8) Bellon & Pouclet 1980; (9) Denaeyer 1959; (10) Denaeyer 1966; (11) Lacroix & Delhaye 1927; (12) Cahen *et al.* 1979; (13) Cahen & Snelling 1966; (14) Agassiz 1954; (15) Antun 1964; (16) Antun 1965b; (17) Biayi-Kalala 1981; (18) Biayi-Kalala 1983; (19) Kampunzu & Vellutini 1981; (20) Ledent & Cahen 1965; (21) Vellutini *et al.* 1981; (22) Liégeois & Biayi-Kalala (in prep.); (23) Lubala & Vellutini 1981; (24) Archives MRAC, Tervuren; (25) Dumba *et al.* 1983 (26) Cahen *et al.* 1975; (27) Tack & De Paepe 1981; (28) Tack & De Paepe 1982; (29) Smirnov *et al.* 1973; (30) Coetzee 1963; (31) Tanzania Geotraverse UNESCO 1983; (32) Brock 1961; (33) Brock 1968; (34) Geological Map Tanzania, Tunduma 1966; (35) Geological Map Tanzania, Itumba (1966); (36) Gittins 1966; (37) Bloomfield *et al.* 1981; (38) Ray 1974; (39) Snelling *et al.* 1964.

series of comparable massifs composed of one or more rock types found in the URAPC and resulting either from one or several intrusions are outcropping along the actual Western Rift (Tack and De Paepe, 1981; Tack *et al.*, 1983; Tack, 1984). The geology and the petrochemistry of some of these massifs are relatively well known whereas for others only limited data are available (table 5). Some carbonatite occurrences reported by Maravic & Morteani (1980) are, in fact, constituted of metasedimentary carbonate rocks (Kibuye; Kawezi) (Verhaeghe, 1963; Bertossa & Neubauer, 1970; Denaeyer, 1970; Lamens, 1981; Archives MRAC, Tervuren) or have a controversial origin (Karonge) (Aderca & Van Tassel, 1971; Van Wambeke, 1977; Brinckmann, pers. comm.; Midende, pers. comm.).

The age, origin and relationships between the massifs and the Western Rift have been the subject of speculation and discussion since their first discovery. For about half of the massifs only a few reliable radiometric ages are available (table 5). A comparison and discussion of the significance of the reported ages should first of all take into account the method of dating used.

As shown above the foidal syenites were emplaced around 740 Ma, not a long time after the outer unit, both units having their Rb-Sr system rehomogenized at about 700 Ma. A similar evolution is proposed for the Kahuzi massif, Zaïre, with a Sr- rehomogenization at about 730 Ma slightly posterior to its emplacement (Liégeois & Biayi-Kalala, in prep.). On other massifs several preliminary Rb-Sr measurements yielded ages between 700 and 600 Ma with some younger values around 500 Ma on biotite.

Some massifs have been investigated by the K-Ar method which gave, with the exception of some younger values (Bellon & Pouclet, 1980), Cambro-Ordovician ages. These results correspond to the younger Rb-Sr data on biotite. Moreover, the URAPC provided a Cambrian K-Ar age for a nepheline syenite (Lubala, pers. comm.).

The K-Ar ages obtained for several massifs reflect then Ar losses during subsequent events and not the emplacement ages.

No Mesozoic alkaline magmatism has been reported yet along the Western Rift whereas it is well-known in the Eastern and Malawi rifts and in the triple junction area of Mbeya-Panda Hill.

From our data and the more reliable ages given in table 5 we may propose comparable Pan-African emplacement ages for the quoted massifs. More radiometric data are needed to specify these points but is is reasonable to think that the 19 complexes are related to the same regional geodynamical event and would indicate that the present Western Rift area was already a zone of weakness in Late Precambrian times. This idea, with respect to the whole East African rift, was already advanced by Dixey (1956) and McConnell (1972) and has been recently integrated into the model of Black *et al.*(1985).

The post-Precambrian evolution of the Western Rift area and the subsequent Cenozoic development of the Western Rift, therefore, must be regarded as a structurally controlled feature superimposed on and reactivating, at least partially, Pan-African taphrogenic lineaments. Whether or not these lineaments are related to Precambrian orogenic belts (McConnell, 1977; Cahen & Lepersonne, 1971; Cahen *et al.*, 1979; Chorowicz & Na Bantu Mukonki, 1980; Villeneuve, 1983; Tack & De Paepe, 1983), and what kind of relationships exist between them, are still points of controversy. In our opinion, an attempt to give an answer to this question seems premature in view of the lack of detailed information on the Pan-African event in the Western Rift area. However, any model to explain the evolution of a Pan-African mobile belt in this part of Africa should take into account that not only in the URAPC but also throughout Burundi (Theunissen & Klerkx, 1983) a phase of Pan-African intraplate deformation is recorded. The latter has been shown to be penecontemporaneous although sligthly earlier than the emplacement of the foidal syenites and the carbonatites. A relationship between this deformation and an uplift with subsequent distensive alkaline magmatism seems therefore likely.

ACKNOWLEDGEMENTS

This study was initiated in 1976 by one of us (L.T.) on the proposal of the late Prof. L. Cahen.

The authors thank the Ministry of Public Works, Energy and Mines of Burundi and, in particular, R. Samoya, Director of the Department of Geology of this Ministry, for facilities during the work.

G. Brouxhon, M. Peric and S. Smejkal (United Nations Development Program, Bujumbura), A. Wolstencroft and A. Mariano (Matongo phosphate project, Bujumbura, with the British Sulphur Corporation Ltd.), G. Midende (Université du Burundi and Université Libre de Bruxelles), P. Van Straaten (Eastern and Southern African Mineral Resources Development Centre, Dodoma, Tanzania) and J. Delhal (Musée royal de l'Afrique centrale, Tervuren) are kindly acknowledged for helpful discussions and exchange of information.

The «Office du Thé du Burundi» contributed to the field survey by providing excellent accommodation at their guest house of Campazi.

R. Black and P. Bowden have reviewed the manuscript and are acknowledged for their helpful criticisms.

REFERENCES

Aderca, B. et Van Tassel, R. (1971) - Le gisement de terres rares de la Karonge. - *Acad. roy. Sci. Outre-Mer, Classe Sc. Nat. et Méd.*, N.S., **18**, 5, 1-117.

Agassiz, J. (1954) - Géologie et pegmatites stannifères de la région de Mumba-Numbi. - *Publ. Com. Nat.* Kivu, Bruxelles, Nouv. Sér., 7, 1-78.

Antun, P. (1960-1961) - Notes de terrain Haute-Ruvubu, Archives M.R.A.C., Tervuren, inédit.

Antun, P. (1964) - Age du volcanisme du Kahuzi-Biega. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1963,* 77.

Antun, P. (1965a) - Quelques considérations sur la géologie des terrains anciens de la crête Congo-Nil au Rwanda et au Burundi. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1964,* 38-42.

Antun, P. (1965b) - Problèmes relatifs à la géologie du Kivu central. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1964,* 42-45.

Bailey, D. (1974) - Continental rifting and alkaline magmatism. - *In* : The Alkaline Rocks, Edit. H. Sorensen, John Wiley and Sons, 148-159.

Bellon, H. et Pouclet, A. (1980) - Datations K-Ar de quelques laves du Rift-ouest de l'Afrique centrale; implications sur l'évolution magmatique et structurale. - *Geol. Rundschau,* **69**, 1, 49-62.

Bennett, J.N. (1981) - The petrology and mineral chemistry of the Shira ring complex, Northern Nigeria. - Ph. D. Thesis, Univ. St. Andrews (Scotland).

Bertossa, A. et Neubauer, W. (1970) - Les gisements de dolomie et de calcaire dolomitique de Kibuye et environs. - *Bull. Serv. géol.* Rwanda, **6**, 7-14.

Biayi-Kalala, W. (1981) - Les trachytes dans les laves acides du Kahuzi (Kivu, Zaïre) : données pétrographiques et chimiques. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1980,* 179-194.

Biayi-Kalala, W. (1983) - Les syénites et les granites du complexe du Kahuzi (Kivu, Zaïre) : données pétrographiques et chimiques. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol., Min. Rapp. ann. 1981-1982,* 47-59.

Black, R., Bonin, B. and Lameyre, J. (1985) - The structural setting of alkaline complexes. - *J. Afr. Earth Sci.* (in press).

Bloomfield, K., Deans, T. and Wells, M. (1981) - The Ilomba Alkaline Complex, northern Malawi and associated Uranium-Niobium mineralisation. *Overseas Geology and Mineral Resources,* **57**, *Institute of Geological Sciences, Natural Environment Research Council,* London, 21 p.

Brock, P. (1961) - A brief summary of the geology of the Mbozi Syenite-Gabbro Complex, Tanganyika. - *Fifth ann. rep. Res. Inst. of Afr. Geol.,* Leeds Univ., 35-39.

Brock, P. (1968) - Metasomatic and intrusive nepheline-bearing rocks from the Mbozi syenite-gabbro complex, southwestern Tanzania. -*Can. J. Earth Sc.,* **5**, 387-419.

Cahen, L. and Snelling, N. (1966) - The geochronology of Equatorial Africa. -*North-Holland Publishing Cy,* Amsterdam, 195 p.

Cahen, L. et Lepersonne, J. (1971) - Données et interprétations nouvelles concernant l'orogenèse katangienne dans le nord-est de la République Démocratique du Congo. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1970,* 71-76.

Cahen, L., Ledent, D. et Snelling, N. (1975) - Données géochronologiques dans le Katangien inférieur du Kasaï oriental et du Shaba nord-oriental (République du Zaïre). - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1974,* 59-70.

Cahen, L. et Ledent, D. (1979) - Précision sur l'âge, la pétrogenèse et la position stratigraphique des «granites à étain» dans l'est de l'Afrique Centrale. - *Bull. Soc. belge Géol.,* **88**, 33-39.

Cahen, L., Ledent, D. et Villeneuve, M. (1979) - Existence d'une chaîne plissée protérozoïque supérieur au Kivu oriental (Zaïre). Données géochronologiques relatives au Supergroupe de l'Itombwe. - *Bull. Soc. belge Géol.,* **88**, 71-83.

Carte géologique du Burundi, feuille Ngozi, 1/100.000, 1983.

Carte des gîtes minéraux du Zaïre, Rép. Zaïre, Département des mines, Service Géologique du Zaïre (1974).

Chorowicz, J. et Na Bantu Mukonki, N. (1980) - Linéaments anciens, zones transformantes récentes et géotectonique des fossés de l'Est Africain, d'après la télédétection et la microtectonique. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1979*, 143-167.

Claessens, W., Fernandez-Alonso, M., Klerkx, J., Liégeois, J.-P., Tack, L. et Theunissen, K. (1981) - La mise en place des granites dans le Kibarien du Burundi et du Rwanda. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1980,* 127-129.

Claessens, W., Dreesen, R., Karayenga, D., Radulescu, I., Theunissen, K. et Waleffe, A. - Notes de terrain des feuilles Ngozi S3/29 SE3 et Gitega S4/29 NE1, Archives M.R.A.C., Tervuren, inédit.

Coetzee, G. (1963) - Carbonatites of the Karema depression, Western Tanganyika. - *Trans. Geol. South Afr.*, 66, 283-340.

de Béthune, P. (1958) - La carbonatite Lueshe (Kivu) : notes pétrographiques. -*Serv. Géol. Congo belge et Ruanda-Urundi,* **Bull.** 8, fasc. 5, 1-8.

Deelstra, H., Katihabwa, J. et Waleffe, A. (1972) - Les sources thermo-minérales au Burundi. -*Bull. Soc. belge Etud. géograph.*, 41, 233-254.

Delhaye, F. et Salée, A. (1928) - Carte géologique de l'Urundi et du Ruanda au 1/200.000^{e}, édit. Patesson et fils, Bruxelles.

Denaeyer, M. (1959) - Les syénites métasomatiques du massif de Kirumba. - *Mém. Acad. Sc. Col.,* **9**, I, 1-234.

Denaeyer, M. (1966) - Sur la présence d'une carbonatite ankéritique (rauhaugite) en bordure du complexe alcalin de Kirumba (Kivu). - *C.R. Acad. Sc. Paris,* **263**, série D, 9-12.

Denaeyer, M. (1970) - Rapports isotopiques delta-O et delta-C et conditions d'affleurement des carbonatites de l'Afrique centrale. - *C.R. Acad. Sc. Paris,* **270**, série D, 2155-2158.

Dixey, F. (1956) - The East African Rift sytem. - *Bull. Suppl. Colon. Geol. Miner. Resour.*, 1, 71 p.

Dumba Kapenda, Caron, J.-P., Kampunzu, A. et Vellutini, P. (1983) - Nouvelles données sur les plutonites de Moba, Kalolo et Lusaka, dans le Nord-Est du Shaba (Zaïre). - *C.R. Acad. Sc. Paris,* **296**, série II, 1429-1434.

Geological map of Tanzania, Quarter degree sheet 257, Tunduma, 1966.

Geological map of Tanzania, Quarter degree sheet 258 and 258S, Itumba, 1966.

Gérards, J. et Ledent, D. (1976) - Les réhomogénéisations isotopiques d'âge lufilien dans les granites du Rwanda. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1975,* 91-103.

Gittins, J. (1966) - Summaries and bibliographies of carbonatite complexes. - *In* : Carbonatites, edit. O. Tuttle and J. Gittins, Interscience Publishers, John Wiley and Sons, 417-540.

Gosseye, A. et Czican, L. (1960) - Archives M.R.A.C., Tervuren, inédit.

Hertogen, J. and Gijbels, R. (1971) - Instrumental neutron activation analysis of rocks with a low-energy photon detector. - *Anal. Chim. Acta,* **56**, 61-70.

International tectonic map of Africa, 1/5.000.000, UNESCO-ASGA, 1969.

Kampunzu, A. et Vellutini, P. (1981) - Mise en évidence d'un complexe annulaire dans le massif du Kahuzi (Sud-Kivu, Zaïre). - *Ann. Fac. Sc. Lubumbashi,* **2**, 75-80.

Klerkx, J. (1983) - The Kibaran in Burundi : a possible model for a proterozoic ensialic belt. - *12th Coll. Afr. Geol.*, Brussels, 6-8 April 1983, Abstr. vol., p. 53.

Klerkx, J., Lavreau, J., Liégeois, J.-P. et Theunissen, K. (1984) - Les granitoïdes kibariens contemporains d'une phase tangentielle au Burundi : un exemple de magmatisme bimodal lié à une distension (ce volume).

Krogh, T.E. (1973) - A low contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determination. - *Geoch. Cosmoch. Acta,* **37**, 485-494.

Lacroix, A. et Delhaye, F. (1927) - Sur l'existence de syénites néphéliniques dans la région de Rutshuru (Graben Central Africain). - *C.R. Acad. Sc. Paris,* **185**, 589-593.

Lamens, J. (1981) - Structure et stratigraphie de la région de Kibuye (Rwanda). - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1980,* 131-145.

Lavreau, J. et Liégeois, J.-P. (1982) - Granites à étain et granito-gneiss burundiens au Rwanda (région de Kibuye) : âge et signification. - *Ann. Soc. Géol. Belg.* **105**, 289-294.

Ledent, D. et Cahen, L. (1965) - Quelques données géochronologiques nouvelles sur des minéraux et roches du Kivu méridional. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1964,* 94-95.

Lepersonne, J. (1974) - Notice explicative de la carte géologique du Zaïre au 1/2.000.000. - *Rép. Zaïre, Département des Mines, Direction de la Géologie.*

Liégeois, J.-P., Theunissen, K., Nzojibwami, E. et Klerkx, J. (1982) - Granitoïdes syncinématiques kibariens au Burundi : étude pétrographique, géochimique et géochronologique préliminaire. - *Ann. Soc. Géol. Belg.*, **105**, 345-356.

Liégeois, J.-P. et Biayi-Kalala, W. (in prep.) - Age du complexe alcalin du Kahuzi (Zaïre).

Lubala, R. et Vellutini, P. (1981) - Données structurales sur le massif du Biega (Kivu-Zaïre). - *Ann. Fac. Sc. Lubumbahi,* 2, 97-102.

Maravic, H.V. and Morteani, G. (1980) - Petrology and geochemistry of the carbonatite and syenite complex of Lueshe (N.E. Zaïre). - *Lithos,* **13**, 159-170.

McConnell, R. (1972) - Geological development of the Rift System of Eastern Africa. - *Bull. Geol. Soc. Am.,* **83**, 2549-2572.

McConnell, R. (1977) - East African Rift System dynamics in view of apparent polar wander. - *J. Geol. Soc.* London, **134**, 1, 33-39.

Meyer, A. (1958) - La carbonatite Lueshe (Kivu) : étude géologique. - *Serv. Géol. Congo belge et Ruanda-Urundi,* **8**, 5, 1-19.

Meyer, A. and de Béthune, P. (1960) - The Lueshe Carbonatite (Kivu, Belgian Congo). - *Intern. Geol. Congress, 21 sess., Proc. part 13,* Copenhagen, 304-309.

Midende, G. (1984) - Pétrologie et géochimie de la carbonatite de Matongo. Thèse de doctorat, Université Libre de Bruxelles, en préparation.

Midende, G. and Demaiffe, D. (1983) - The carbonatite intrusive body of Matongo, Burundi (Central-East Africa). - *12th Coll. Afr. Geol.,* Brussels, 6-8 April, 1983, Abstr. vol., p. 69.

Ntungicimpaye, A. (1981) - Contribution à l'étude lithostratigraphique du Burundien inférieur dans la région de Mageyo (Burundi). - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1980,* 161-171.

Ntungicimpaye, A. (1983) - Le magmatisme basique d'âge protérozoïque de la région de Mageyo (Burundi) : données pétrographiques et géochimiques. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1981-1982,* 119-126.

Ntungicimpaye, A. (1984a) - Le magmatisme basique dans le Burundien de l'Ouest du Burundi. - *UNESCO, Geology for Development, Newsletters,* **3**, 13-21.

Ntungicimpaye, A. (1984b) - Contribution à l'étude du magmatisme basique dans le Kibarien de la partie occidentale du Burundi. - Thèse de doctorat, Rijksuniversiteit Gent, 250 p.

O'Nions, R.K., Hamilton, P.J. and Evensen, N.M. (1977) - Variations in $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios in oceanic basalts. - *Earth Planet. Sci. Lett.* **34**, 13-22

Poldervaart, A. and Taubeneck, W.H. (1960) - Layered intrusions. - *Intern. Geol. Congress, 21 sess., Proc. part 13,* Copenhagen, 239-246.

Radulescu, I. (1981) - Carte géologique du Burundi, 1/500.000, Projet de recherches minières, UNDP, Bujumbura.

Ray, G. (1974) - The structural and metamorphic geology of northern Malawi. - *J. Geol. Soc.* London, 130, 427-440.

Richard, P., Shimizu, N. and Allegre, C.J. (1976) - $^{143}Nd/^{146}Nd$, a natural tracer : an application to oceanic basalts. - *Earth Planet. Sci. Lett.* **31**, 269-278.

Rombouts, L. (1982) - Prospection minière sur le complexe syénitique au sud de Kayanza. Projet de Recherches minières. Rapport confidentiel UNDP, Bujumbura, inédit.

Scarlat, L. (1977) - Rapport géologique sur les sondages de Matongo. Projet de recherches minières, UNDP, Bujumbura, inédit.

Smejkal, S. (1979) - Synthèse des travaux de recherches sur les minéralisations associées aux carbonatites de Matongo-Bandaga. Projet de recherches minières, UNDP, Bujumbura, inédit.

Smirnov, V., Pentelkov, V., Tolochko, V., Trifan, M. and Zhukov, S. (1973) - Geology and Minerals of the central part of the western rift : Report on the geological mapping. Mineral Resources Division, Ministry of Commerce and Industries, Dodoma, Tanzania, inédit.

Snelling, N., Hamilton, E., Drysdall, A. and Stillman, C. (1964) - A review of age determinations from Northern Rhodesia. - *Econ. Geol.,* 59, 6, 961-981.

Tack, L. (1984) - Post-Kibaran intrusions in Burundi. - *UNESCO, Geology for Development, Newsletters* **3**, 47-57.

Tack, L. et De Paepe, P. (1981) - Le massif intrusif de syénites foïdales de la Haute-Ruvubu (Burundi). - Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1980, 173-178.

Tack, L. and De Paepe, P. (1982) - The alkaline plutonic complex of the Upper Ruvubu (Burundi) : presentation of the geological map and discussion. - *Geological Society of Africa (G.S.A.), 6th Conference on African Geology,* Nairobi, Kenya, 11-19 December 1982, Abstr. vol.

Tack, L. et De Paepe, P. (1983) - Le volcanisme du Sud-Kivu dans le nord de la plaine de la Rusizi au Burundi et ses relations avec les formations géologiques avoisinantes. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1981-1982,* 137-145.

Tack, L., Deutsch, S., Liégeois, J.-P. and De Paepe, P. (1983) - Age, Nd and Sr isotopic geochemistry of the alkaline plutonic complex of the Upper Ruvubu (Burundi). - *12th Coll. Afr. Geol.,* Brussels, 6-8 April 1983, Abstr. vol., p. 96.

Tanzania : Geotraverse in the proterozoic belts of Western Tanzania (1983) - *UNESCO, Geology for Development, Newsletters,* **2**, 12-17.

Theunissen, K. ((984) - Les principaux traits de la tectonique kibarienne au Burundi. - *UNESCO, Geology for Development, Newsletters,* 3, 25-30.

Theunissen, K. et Klerkx, J. (1980) - Considérations préliminaires sur l'évolution tectonique du Burundien au Burundi. - *Mus. roy. Afr. centr., Tervuren, Dépt. Géol. Min., Rapp. ann. 1979,* 207-214.

Theunissen, K. and Klerkx, J. (1983) - Pan-African and late Kibaran tectonics in Western Burundi. - *12th Coll. Afr. Geol.,* Brussels, 6-8 April 1983, Abstr. vol., p. 97.

Thoreau, J. (1931) - Une syénite néphélinique de l'Urundi. - *Bull. Soc. belge Géol.,* 41, 262-265.

Thoreau, J. (1932) - Le massif alcalin de la Haute-Ruvubu (Urundi). - *Bull. Acad. Roy. Belg., Cl. Sc., 5e sér.,* 18, 10, 877-883.

Van Wambeke, L. (1977) - The Karonge Rare Earth Deposits, Republic of Burundi : New mineralogical-geochemical data and origin of the Mineralization. - *Mineral. Deposita,* 12, 373-380.

Vellutini, P., Bonhomme, M., Caron, J.-P., Kampunzu, A. et Lubala, T. (1981) - Sur la signification «tectonique» des complexes alcalins acides du Kahuzi et du Biega (Kivu, Zaïre). - *C.R. Acad. Sc. Paris,* 292, série II, 1027-1029.

Verhaeghe, M. (1963) - Inventaire des gisements de calcaires, dolomies et travertins du Kivu, du Rwanda et du Burundi. - *Rép. du Congo, Minist. Terres, Mines et Energie, Direction du Service Géol.,* Mémoire n° 3, 95 p.

Villeneuve, M. (1983) - Les sillons tectoniques du Précambrien supérieur dans l'est du Zaïre; comparaisons avec les directions du Rift est-africain. - *Bull. Centres Rech. Explor., Prod. Elf-Aquitaine,* 7, 1, 163-174.

Weis, D. and Deutsch, S. (1984) - Nd and Pb isotope evidence from the Seychelles granites and their xenoliths : mantle origin with slight upper-crust interaction for alkaline anorogenic complexes. - *Isotope Geosciences,* 2, 13-35.

Weis, D., Liégeois, J.-P. and Black, R. (in press) - Deep mantle origin and U/Pb isochrones for a continental alkaline ring complex (Tadhak, Mali).

Williamson, J.H. (1968) - Least-square fitting of a straight line. - *Can. J. Phys.* 46, 1845-1847.

L. TACK. *Université du Burundi, Faculté des Sciences, Département Géologie et Minéralogie, B.P. 2948, Bujumbura, Burundi.*

P. DE PAEPE. *Laboratorium voor Aardkunde, Rijksuniversiteit Gent, Krijgslaan 281, B-9000 Gent, Belgium.*

S. DEUTSCH. *Laboratoires Associés Géologie - Pétrologie - Géochronologie, Université Libre de Bruxelles, Av. Fr. Roosevelt 50, B-1050 Bruxelles, Belgium.*

J.-P. LIEGEOIS. *Service de Géochronologie, Musée royal de l'Afrique centrale, B-1980 Tervuren, Belgium.*

GEOLOGIE AFRICAINE

Volume en hommage à L. CAHEN

Edité par J. KLERKX et J. MICHOT

AFRICAN GEOLOGY

A volume in honour of L. CAHEN

Edited by J. KLERKX and J. MICHOT

Musée royal de l'Afrique centrale - Tervuren
1984