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CRUSTAL EVOLUTION OF THE NORTHERN KIBARAN BELT, EASTERN AND CENTRAL AFRICA

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Abstract. The Kibaran belt in Burundi is composed of pelitic and quartzitic rocks intruded by large amounts of granites. During an early phase of its evolution the belt has undergone a major tectonic event, resulting in a regional horizontal foliation and a decollement of the sedimentary cover over its basement. Large amounts of granitic magmas associated with mafic intrusives have been intruded contemporaneously with the tectonic deformation. These early structures are considered to result from extension of the lithosphere. Granitic magmas were formed by melting of the lower crust as a result of heat transfer from mafic magmas generated during the extension. The early granitic magmatism started around 1350 Ma ago and reached its paroxysm about 1260 Ma ago. A compressive phase, associated with granitic magmatism and causing upright NE-SW oriented folding, occurred around 1180 Ma ago. Mafic and ultramafic intrusions as well as alkaline granites are associated with a phase of lateral shear affecting the area around 1100 Ma. The Kibaran belt is interpreted to have evolved entirely in an intracontinental environment. It started as an extensional basin, evolving into an extension belt with intensive granitic and mafic magmatism. The late compressive phase, and particularly the late shear, are considered to result from continental collision to the SE which occurred in the southern Malawi-Moçambique belt during the same period. Collision in the south resulted, in the northern Kibaran belt, in delamination of the lithosphere, intrusion of asthenosphere into the continental lithosphere and strike-slip movements; this resulted, in turn, in the formation of shear zones in the upper crust and intrusion of ultramafic and alkaline magmas.

Introduction

The Kibaran orogeny affected large areas of central, eastern and southern Africa. It occurred during the Middle Proterozoic, starting probably around 1400 Ma with the first phases of basin formation and associated magmatism, whereas the maximum intensity of deformation occurred around 1100 Ma. Although the Kibaran orogeny was initially defined in the Kibara Mountains of Shaba (Zaire), it has now been recognized that several linear and mostly parallel belts of Kibatan age exist in the eastern part of Africa (Fig. 1). The northern of the belts of this age, which is considered here, extends in a NE direction from Shaba (Zaire) through Burundi and Tanzania to Rwanda, where it swings to the NW, ending in Uganda and northern Zaire.

Over its whole length the belt is composed predominantly of low-grade pelites and quartzites with only minor calcareous and volcanic sequences. This assemblage constitutes the Burundi or Karagwe-Ankole Supergroup. Large intrusions of granitoid rocks are common as well as mafic and ultramafic bodies. The area investigated in Burundi is representative, from the point of view of lithology, structure and magmatism, of that section of the belt which extends through Tanzania, Rwanda and Uganda.

The aim of the paper is to give an overview of the main structural and magmatic characteristics of the belt which is considered here as an intracontinental fold belt.

Kibaran structural and magmatic events in this region are long-lived, extending from 1350 to 1100 Ma (Klerkx et al., 1984). In our interpretation the belt acquired its main structural and magmatic characteristics during an early phase of décollement tectonics, occurring between 1350 and 1250 Ma ago; during this major phase of deformation, granitic intrusions were emplaced in different phases.

Décollement tectonics and associated magmatism are discussed as resulting or from compressional or extensional processes. Arguments are presented favouring the extension hypothesis.

During a later period (around 1180 Ma ago), limited shortening occurred with the development of upright folds. A later shear event occurred around 1100 Ma and was responsible for the development of intense but narrow shear zones.

Brief Geological Outline of the Region

The Kibaran belt in this region (Fig. 2) is separated from its foreland - the Tanzanian craton - to the east by flat-lying sediments (Malagarasian in Burundi, Bukoban in Tanzania) of Upper Proterozoic age. In east and south west Burundi the Burundi Supergroup overlies the Archaean basement

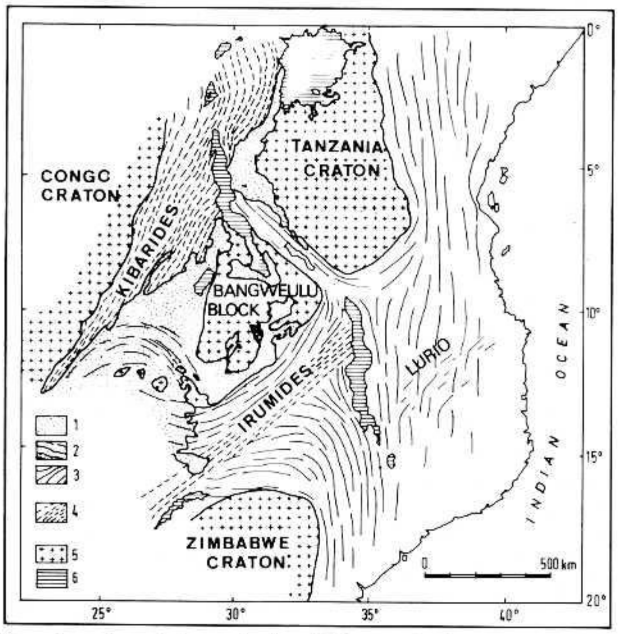

Fig. 1. Location of the Kibaran belt in central and eastern Africa (modified after Cahen and Snelling, 1984). 1. Tabular Upper Precambrian; 2. Folded Upper Precambrian; 3. Formations older than the Upper Precambrian affected by Upper Precambrian events; 4. Kibarides and Irumides; 5. Zones cratonized since at least 1800 Ma ago; 6. Lakes in the Eastern Rift.

(Demaiffe and Theunissen, 1978) which is composed of mainly migmatitic gneisses locally containing granulite facies remnants. These gneisses suffered a complex structural evolution with extensive reworking during the Kibaran (Nzojibwami, 1984). The Burundi Supergroup consists mainly of pelitic rocks with quartzitic intercalations of various thicknesses. The lower and middle divisions of the Burundian pile reach a thickness of 8 to 10 km; they start with a sequence of quartzites more than 1 km in thickness, followed by mainly pelitic sediments. Thin layers of calcareous sediments are restricted to the NW part of the region. Volcanic sequences are rare : a thin intercalation (a few ten of meters) of dacitic to rhyodacitic volcanoclastic rocks is known in the lower part of the sedimentary sequence in the eastern part of the belt. More widespread are basic volcanics situated in the upper part of the middle Burundian which are continuously present in western Burundi but are absent in the east. Locally associated with these mafic volcanics are volcanics of acid to intermediate composition. They have recently been studied in detail in some sections by Ntungicimpaye (1984a; 1984b) who describes them as flows and pyroclastic rocks with tholeiitic composition.

The lower and middle Burundian sediments are mature, well sorted and mainly fine grained sediments. The upper division of the Burundian, 3 to 4 km thick, also comprises quartzites and pelites, but the arenites are often immature, generally badly sorted and commonly contain conglomeratic layers.

Granitic rocks are concentrated in the western part of Burundi where they form extensive and complex intrusions that are always associated with smaller mafic intrusions. They are intrusive mainly in the lower part of the Burundian sequence. In the eastern part of the country granitic intrusions are isolated and form more homogeneous bodies.

Large mafic and ultramafic bodies are restricted to the eastern part of the region. A set of large intrusions are elongated along a NE direction, parallel with the major Kibaran structural trend. Ultramafic rocks (peridotites) are always associated with layered intrusions of gabbros, norites, leuconorites and anorthosites. This linear alignment of mafic intrusions extends northwards into Tanzania as far as Lake Victoria.

The metamorphism, which is incipient in the east, increases westwards and reaches its maximum of intensity in the vicinity of granitoid complexes. Plurifacial metamorphic mineral assemblages comprising andalusite, staurolite, chloritoid, biotite and garnet exist in regions where granitoids are abundant.

Several superimposed mineral parageneses have been observed (Willems, 1985) : the most common association is andalusite-muscovite, belonging to the cordierite amphibolite facies, with superimposed crystallisation of sillimanite in the high-T amphibolite facies. The association staurolite-chloritoid appears as a retrograde paragenesis. Locally (SW Burundi) the association staurolite-almandine-kyanite-biotite has been observed as a remnant of a first phase of metamorphism.

What concerns the distribution of the metamorphism, it is worth noting that there is no gradual increase in metamorphism, although the metamorphic grade is higher in the W. Increased metamorphism is restricted to particular areas in association with the presence of abundant granitic intrusions.

The structural evolution of the Kibaran belt is characterized by three successive phases of deformation (Theunissen, 1984) : the first phase of horizontal deformation (D1) is particularly well expressed in the more strongly metamorphosed parts of the western region. It is documented mainly by the development of bedding-parallel foliation and by local small intrafolial folds. In the regions of intense granitic plutonism, structures related to thin-skinned thrusting are observed. In the less metamorphosed eastern region the regional schistosity is much less developed and the D1 formation is mostly expressed by a décollement of the cover over the Archaean basement, resulting in the mylonitisation of the basement at the contact. Details of this phase of deformation will be given in a later section. In the western region numerous granite intrusions were emplaced or foliated parallel to the D1 foliation.

The second phase (D2) produced open, upright folds mainly oriented NE-SW, locally swinging to

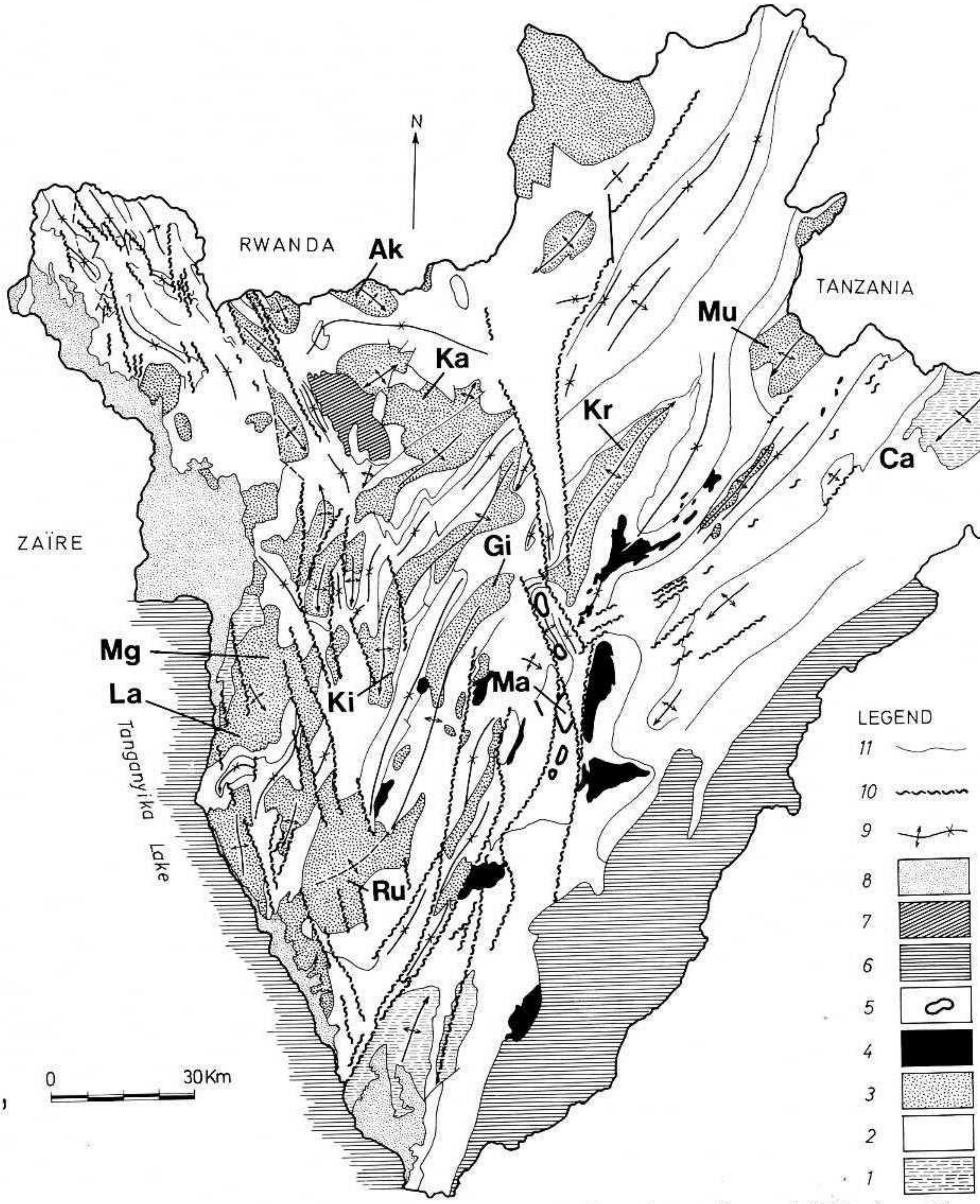

Fig. 2. Major structural and magmatic characteristics of the Kibaran belt in Burundi. 1. Archaean; 2. Burundian metasediments; 3. Kibaran granitoids; 4. Mafic and ultramafic intrusions; 5. Late-Kibaran alkaline intrusions; 6. Malagarasian (post-Kibaran) sediments; 7. Post-Kibaran alkaline complex; 8. Cainozoic; 9. Principal axes of upright folding (D2); 10. Principal late-Kibaran shear zones (D2'); 11. Stratigraphic limits and structural trends. Abbreviations on the map refer to the location of analysed samples (see also Fig. 3 to 7) : Ca : Cankuzo, Ka : Kayanza, Ru : Rumeza, Mu : Muramba, Ak : Akanyaru, La : Lake, Mg : Mugere, Ki : Kiganda, Kr : Karuzi, Ma : Makebuko, Bu : Bururi.

NW-SE. This deformation is the most obvious expression of the Kibaran belt and defines its major physiographic features. The regular trends of these folds are deflected around granite-gneiss domes which were mostly emplaced during the D1 deformation. The D2 deformation is generally not sufficiently penetrative to obliterate the D1 structures.

A late shear (D2') was locally superimposed on the earlier structures, producing vertical shear zones oriented NE-SW or NW-SE. Alkali granite intrusions (Tack and De Paepe, 1983; Tack, 1984) are spatially associated with the shear zones and in places are affected by them. The nature and significance of this shear will be discussed later.

Granitoids Associated With D1 Deformation

Two types of early Kibaran granitoids can be distinguished. The first type (Gr 1) consists of biotite granite forming relatively homogeneous batholiths. Their relations with the surrounding rocks are generally difficult to define because of the intense deformation which affected both the granites and the surrounding sediments. The granitic rocks are commonly mylonitic and locally are phyllonites. Their strong deformation attests to emplacement early in the Kibaran tectonic evolution, even possibly before the onset of D1 deformation.

The second type (Gr 2) is much more abundant and, particularly in West-Burundi, constitutes large batholitic complexes which are heterogeneous in texture but whose composition is nearly constant (usually two mica granites). Another feature in common is that their magmatic or metamorphic foliation is always parallel with the bedding and the schistosity of the adjoining sediments. Their heterogeneous aspect results from variations in texture, from mylonitic to a primary parallel alignment of idiomorphic feldspar phenocrysts. Another common character of the Gr 2 granitoids is the presence of metasedimentary inclusions, mostly quartzite. Some granites even contain parallel, decimetre-scale lenses of quartzite, indicative of the partial assimilation of the metasediments into which the granites were intruded. Mafic rocks, amphibolites or amphibole gabbros are always associated with these granitoids.

Evidence for Synkinematic Emplacement of the Gr 2 Granitoids

Whereas the Gr 1 granites occur in homogeneous bodies which, according to their mylonitic texture, are probably pre-kinematic with respect to the Kibaran D1 deformation, the Gr 2 granitoids present many characteristics in favour of a synkinematic emplacement with respect to this deformation. As stated above, they are often made up of different units of texturally different granitoids, but whose parallel contacts are concordant with the overlying sediments. Their internal texture is also always parallel with the subhorizontal D1-related foliation in the metasediments.

If the internal structure of some Gr 2 granitoids is doubtless of metamorphic origin (gneissic or mylonitic texture), it is however of magmatic origin in most granitoids. This is best expressed by the granites with well oriented idiomorphic feldspar phenocrysts swimming in an entirely magmatic textured matrix. The synkinematic character of this family is confirmed by some of the porphyritic granites which present a protoclasis (cataclasis occurring during the crystallisation and emplacement of the magmas). Indeed, in these rocks the feldspar phenocrysts, which are macroscopically idiomorphic, consist of an aggregate of isometric crystals with different optic orientation. On the other hand, the matrix around these cataclastic phenocrysts consists of elongated quartz and undamaged plagioclase crystals associated with oriented micas and presents a magmatic texture. The two micas, biotite and muscovite form large and intimely intermixed flakes. They also are oriented along the D1 direction and are considered as resulting from magmatic crystallisation.

The presence in the granitoid complexes of rocks of different texture but with a constant foliation parallel to that of the surrounding metasediments and the presence within these complexes of rocks whose orientation has a magmatic origin suggest that these granitoids were emplaced and partially deformed during the phase of deformation resulting in the regional foliation of the metasediments (D1). This horizontal movement must have persisted over the whole period of time of granite emplacement. This means that the granites emplaced early in this process were already consolidated and have been fracturated and eventually recrystallised under the influence of the persistent movement; the latest phases of granite have not undergone this fracturation and have still preserved their magmatic texture.

The Nature of the Granitic Intrusions

Most of the Gr 1 granitoids have granite compositions and few are granodiorites (Fig. 3a). The rocks are generally coarse grained, contain large microcline and zoned plagioclase crystals and are rich in biotite. Accessory minerals include sphene, zircon and apatite. Granodioritic rocks are found as inclusions in the granites; they are often finer grained, porphyritic and contain large amounts of biotite. These rocks are often mylonitized and then contain secondary muscovite.

The Gr 2 granitoids, although very variable in texture, present a homogeneous mineralogy; these leucocratic granitoids (Fig. 3b) contain large and abundant feldspar phenocrysts, are rich in muscovite and contain variable amounts of biotite. They are also characterized by numerous inclusions of metasedimentary rocks, particularly quartzites, and locally contain decimetre-scale parallel lenses of quartz which are considered remnants of incompletely resorbed metasediments. Tourmaline is ubiquitous. This attests to an interaction of the granitic liquid with the surrounding sediments.

Chemically, although all the investigated gra-

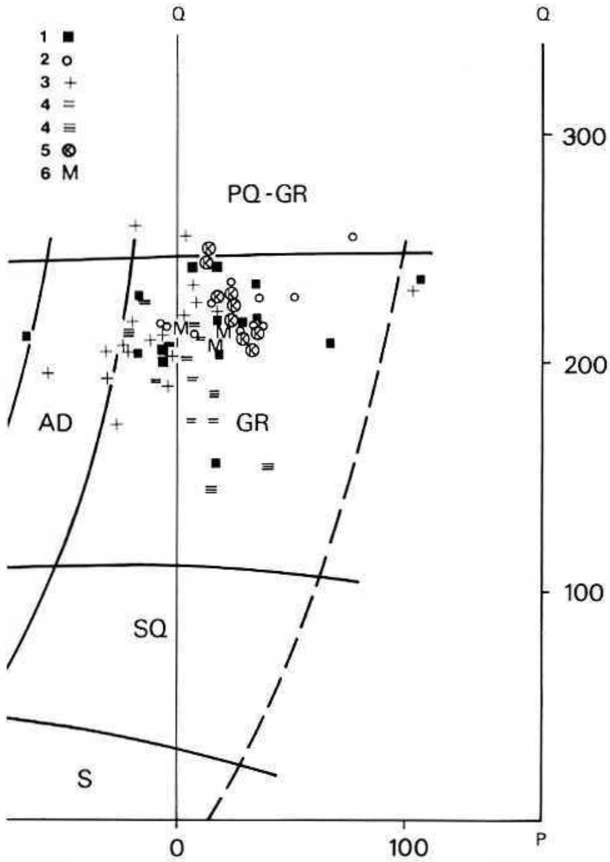

Fig. 3a. The Kibaran granitoids in the chemical-mineralogical classification for plutonic rocks of Debon and Le Fort (1983). Most granitoids are real granites s.s., mainly quartz-rich, some of them per-quartzose. Adamellitic or other types are scarce. Symbols : 1 : Ka and Ru (Gr 1), 2 : Mu and Kr (Gr 2), 3 : La (Gr 2), 4 : Mg (Gr 2), 4' : also Mg, samples from single outcrop, 5 : Ki and Gi (syn-D2), 6 : Ma (syn-D2'). PQ-GR = perquartzose granites, GR = granites, AD = adamellites, SQ = quartz syenites, Q = Si/3 -K-Na-2/3Ca. P = K-Na-Ca.

nites have a peraluminous composition, it is stronger in the Gr 2 granites. Another aspect of the Gr 2 granites is their very variable composition and generally high normative quartz content. This is expressed in the Q-Ab-Or diagram (Fig. 5) by the large area covered by the granite composition and the shifting of the points towards the Q pole relatively to eutectical.compositions.

To evaluate the dispersion of the chemical composition, the rock compositions have been plotted on a c versus q/or+ab+or diagram (normative compositions) (Fig. 4). In this diagram c expresses the peraluminous character while q/or+ab+an represents the deviation of the compositions away from the ternary granitic minimum composition as result of high quartz content. In this diagram the Gr 2 granites are dispersed over a large area, varying from compositions close to common S-type granites such as the Manaslu leucogranite (Le Fort, 1981) towards granites strongly enriched in corundum and quartz. The extreme values are close to those of metasediments. In this diagram individual massifs appear to form separated lineages. This is best expressed in the Mugere granite; some compositions fall in the field of low peraluminosity whereas others move to compositions enriched in Al and Si. The high peraluminosity is interpreted as the result of a contamination of the granitic magma by metasediments, locally present as residual lenses. The field occurrence of the Gr 2 granites (sheets intercalated in the metasediments) and the spatial variation in composition of one single massif suggest that the contamination with the metasediments occurred essentially during the emplacement of the granites. This implies that it is difficult to deduce the magmatic source composition from the rock composi-

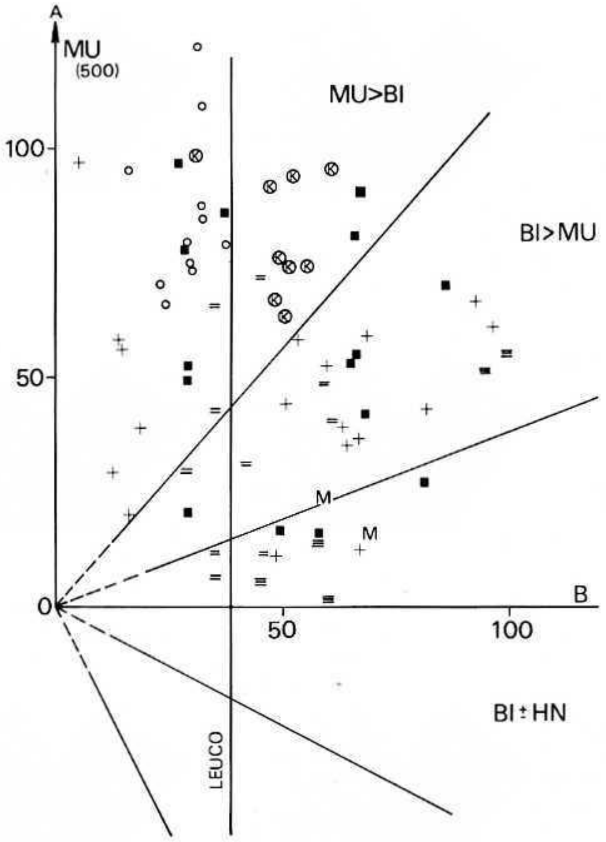

Fig. 3b. The Kibaran granitoids in the chemical-mineralogical classification for magmatic associations of Debon and Le Fort (1983). All granites are peraluminous, with variable muscovite to biotite ratios. No definite trend can be detected, neither between granite units, nor within a particular one. This feature is attributed to the effects of contamination by sediment assimilation (see text for explanation). MU = muscovite, BI = biotite, HN = hornblende. A = Al-K-Na-2Ca, B = Fe+Mg+Ti.

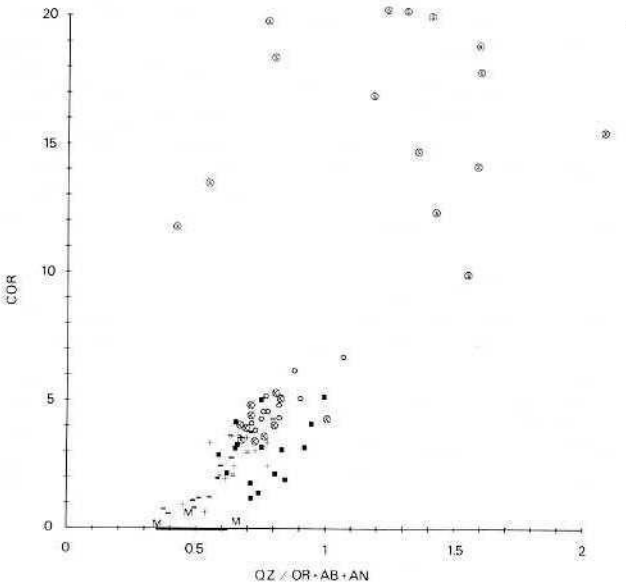

Fig. 4. The Kibaran granitoids compared to a variety of sediments of the Burundi Supergroup, likely to represent contaminants. The diagram expresses (a) the peraluminosity due to the assimilation of Al-rich sediments giving rise to corundum-normative rocks (b) the perquartzosity due to the assimilation of quartz-rich rocks, giving rise to a quartz to feldspar ratio above normal (heavy line in diagram) eutectic values.
COR, QZ, AB, AN and OR are CIPW-normative values. Symbols as in Fig. 3a.

tion. Nevertheless, the contamination trend leads to estimate a non peraluminous original magma.

Age of the Gr 1 and Gr 2 Granites

In earlier papers age data on magmatic events in the Kibaran belt have been presented for Shaba (Zaire), Rwanda and Uganda (for an overview see Cahen and Snelling, 1984). The ages of the Kibaran tectonic events have been deduced from these data in conjunction with preliminary structural studies.

According to the previous studies the ages of magmatism in the Kibaran belt range between early and syntectonic granites; i.e. between 1366 ± 32 Ma and 1289 ± 31 Ma (data obtained on granites from Rwanda and Uganda) (Cahen et al. 1967, 1972; Vernon-Chamberlain and Snelling, 1972) and 970-990 Ma for tin-bearing leucocratic granites of Shaba and Rwanda (Gérards and Ledent, 1970; Cahen and Ledent, 1979; Lavreau and Liégeois, 1982). However, as these late granites intrude Upper Proterozoic sediments in Zaire, they rather belong to the Katangan orogenic event than the Kibaran orogeny (Cahen and Ledent, 1979; Lavreau and Liégeois, 1982).

New age data on early granites in Burundi have recently been given by Klerkx et al. (1984), based on detailed field and isotopic investigations of these granites. A preliminary minimum zircon age (Ledent, 1979) obtained on the Gr 1 type-massif (Rumeza) suggests that this intrusion was emplaced around 1325 Ma ago (two zircon fractions with t ^{207}Pb/^{206}Pb = 1335 Ma and 1319 Ma). A Rb-Sr isochron (Klerkx et al. 1984) (Fig. 6b) gives an age of 1268 ± 44 Ma for the same body. As this granite is highly cataclastic and often mylonitic, this age is interpreted as a product of resetting during the D1 deformation. A second Gr 1 granite, the Kayanza pluton, gives an Rb-Sr isochron age of 1330 ± 30 Ma (Fig. 6c). As the Kayanza pluton is much less affected by mylonitisation than the Rumeza massif, this age probably corresponds to the age of emplacement of the granite. The age data indicate that the Gr 1 granites were emplaced before D1 deformation; some of them were intensely mylonitized by this event (Rumeza), which resulted in a resetting of the ages, while others (Kayanza) were less affected.

The beginning of sedimentation in the Burundian basin is estimated to have occurred not long after 1400 Ma ago. This evaluation is based on a Rb-Sr age obtained on rhyodacitic volcanic rocks (location Cankuzo, see Fig. 2) interbedded with the lower Burundian sediments in eastern Burundi where the D1 deformation and metamorphism are absent. These volcanic rocks give an isochron age of 1353 ± 46 Ma (Fig. 6a), which probably corresponds to

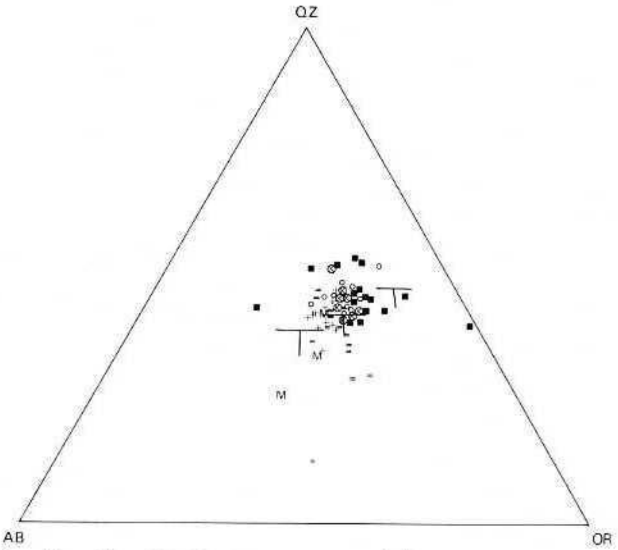

Fig. 5. The QZ-AB-OR ternary minima at 1kb water pressure (James and Hamilton, 1969). Most granites plot near one or other cotectic line, indicating that they were indeed liquids, but deviations within one particular granitic unit can be important. This situation is attributed to the overwhelming effect of assimilation of quartz and/or aluminous rocks, the conditions of crystallisation of the various units being similar as well as their chemical composition. Ternary minima are indicated for AN contents of (from left to right) 3, 5 and 7.5 per cent of the sum quartz plus feldspars. Symbols as in Fig. 3a.

TABLE 1. Rb and Sr Isotopic Data (New Results)

Sample	Rb	Sr	^{87}Sr/^{86}Sr	^{87}Rb/^{86}Sr
		MAKEBUKO GRANITE		
63 866	216	114	0.7941 ± 3	5.53
71 352	222	120	0.7938 ± 2	5.40
LT 4	187	141	0.76968 ± 4	3.86
LT 22	180	131	0.76517 ± 8	4.00
LT 23	177	141	0.76538 ± 4	3.65
LT 26	218	138	0.78276 ± 5	4.60
WC N2	158	158	0.75580 ± 3	2.91
		BUKERASAZI GRANITE		
LT 2	183	13.65°	1.40348 ± 16	41.46
LT 7	225	16.34°	1.37049 ± 5	42.45
		BURURI MYLONITES		
71 720A	131	50.9	0.87496 ± 5	7.57
71 720B	184	49.9	0.92758 ± 4	10.90
71 720C	162	78.6	0.85149 ± 4	6.05
		AKANYARU CHLORITOID SCHISTS		
JPL 190	288	54.0	0.97407 ± 4	15.84
JPL 191	310	57.5	0.98731 ± 5	16.03
JPL 192	290	59.5	0.96363 ± 4	14.46
JPL 193	240	60.2	0.92149 ± 5	11.78
JPL 195	329	54.5	0.99745 ± 6	17.97
JPL 198	183	53.2	0.89988 ± 4	10.14
JPL 200	299	66.3	0.94083 ± 4	13.35

- Rb and Sr concentrations were determined by XRF (C. Léger, analyst), except (°) by isotope dilution.
- The errors on the ^{87}Rb/^{86}Sr ratios are 2%.
- NBS 987 standard : 0.710235 ± 0.000026.
- Normalisation for ^{86}Sr/^{88}Sr = 0.1194.
- ^{87}Rb = 1.42 $10^{-11}a^{-1}$.
- Isotopic ratios were measured on the VARIAN MAT 260 and VARIAN TH5 mass spectrometers of the Centre Belge de Géochronologie, Brussels.
- The ages and initial ratios were calculated following the method of Williamson (1968).
- All the errors are quoted at the 2σ level.

the age of diagenesis or incipient metamorphism. They are derived from tuffs and tuffites which were composed originally of glass shards which have partly recrystallized during incipient metamorphism.

The Gr 2 granites, which are intruded synkinematically with respect to the D1 deformation, all give similar ages around 1260-1280 Ma (Mutumba, Mugere, Lac : Liégeois et al. 1982, see Fig. 6d; Muramba and Akanyaru : Klerkx et al. 1984, see Fig. 6e and 6f). These ages most likely correspond to the D1 horizontal deformation; the ages represent either the time of synkinematic emplacement of the granites or the age is reset by the deformation climax which occurred shortly after the emplacement of the granitic intrusions.

The Origin of the Gr 1 and Gr 2 Granites

The contamination undergone by the granitic magmas, particularly those at the origin of the Gr 2 granites, restricts a discussion on the nature and the origin of the primary magmas. The strong peraluminous composition which characterizes all these granites has certainly been obtained at least partly when the granitic magma interacted with the Burundian sediments during intrusion (see above and Fig. 3 to 5). An evaluation of the degree of the

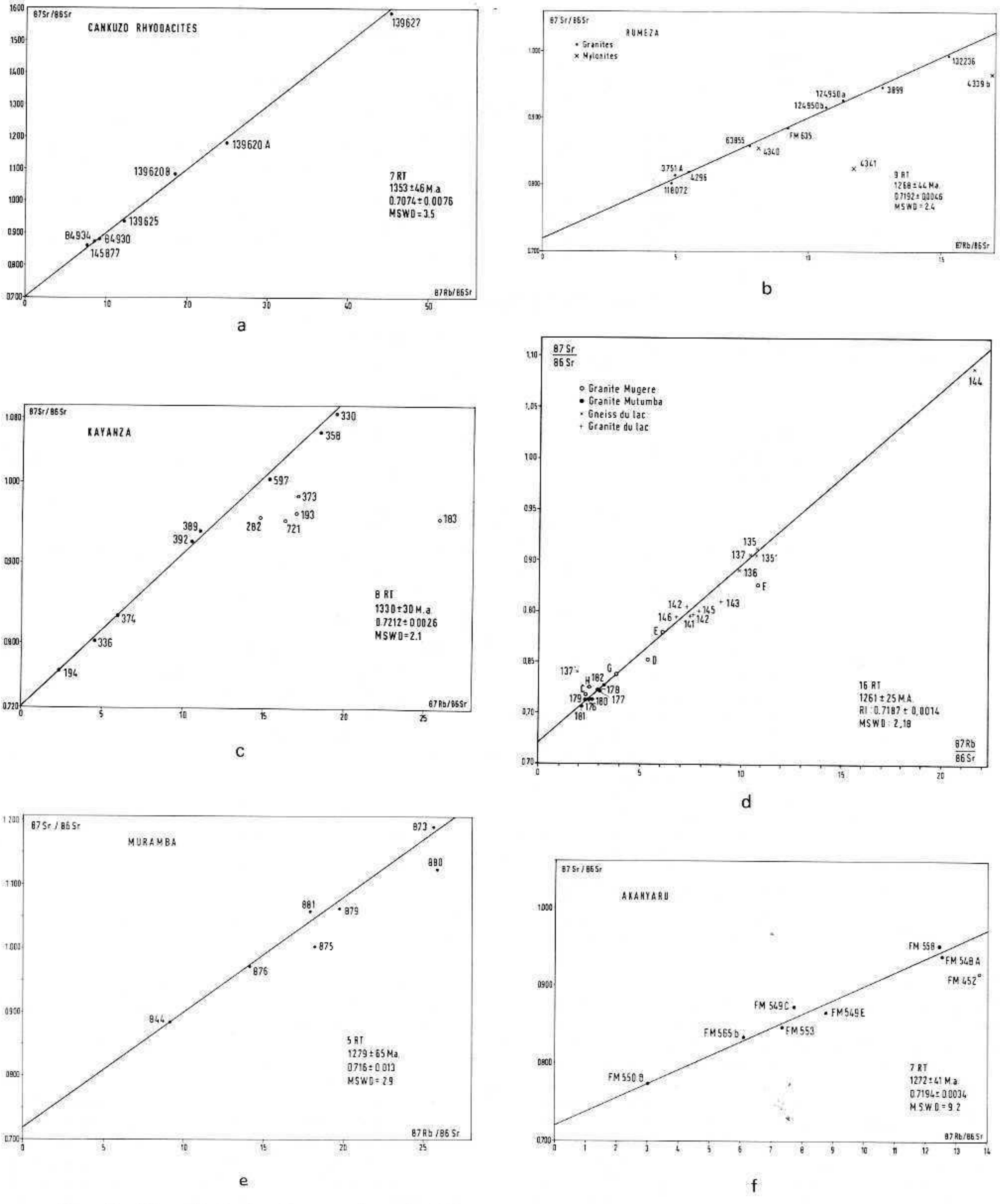

Fig. 6a-6f. Rb-Sr isochrons of early Kibaran magmatic rocks. a. Cankuzo metavolcanics; b. Rumeza Gr 1 granite; c. Kayanza Gr 1 granite; d. Mutumba-Mugere-Lac Gr 2 granite; e. Muramba Gr 2 granite; f. Akanyaru Gr 2 granite. Localities in Figure 2.

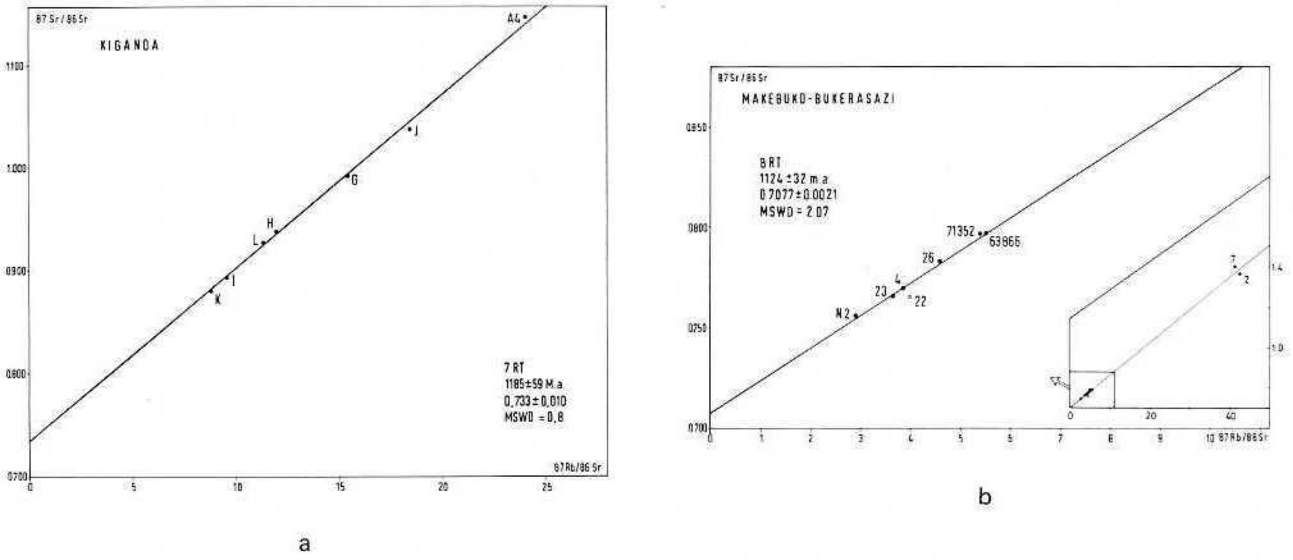

Fig. 7a–7b. Rb-Sr isochrons of late Kibaran rocks and events. a. syn-D2 Kiganda granite; b. Makebuko-Bukerasazi alkaline intrusions (provisional isochron). Localities in Figure 2.

contamination and of its effects on the magma composition has not yet been made. It is therefore not possible to evaluate exactly the original magma composition.

Nevertheless, it appears that the initial $^{87}Sr/^{86}Sr$ ratios of the different granites are relatively low, particularly in view of the highly peraluminous composition which resulted, in part at least, from contamination by crustal material. The Rumeza Gr 1 granite has an initial ratio of 0.707-0.710 (recalculated at 1325 Ma) which corresponds to the ratio of the early Cankuzo volcanics (0.707). A lower crustal origin for these magmas has to be taken into account (Klerkx et al.,1984). The Gr 1 Kayanza granite and the analyzed Gr 2 granites have initial Sr isotopic ratios between 0.716 and 0.721. These ratios are also relatively low considering that these magmas have been strongly contaminated by crustal material. It has been suggested (Klerkx et al.,1984) that the primary magma from which these granites were originated was derived from a low radiogenic source, probably in the lower continental crust, and that they have been progressively contaminated by crustal material, but essentially during their emplacement.

D1 Deformation: Extensional Tectonics or Thrust-Related Deformation?

Characteristics of the D1 deformation. The D1 deformation is most strongly expressed in the more metamorphic western part of the investigated region where Gr 1 and Gr 2 intrusions are abundant. In the less metamorphic eastern part a schistosity parallel to bedding is restricted to the contact zones between the Archaean basement and the Burundian sedimentary cover : a narrow zone of mylonites is developed in the basement adjacent to the cover and in the basal quartzite of the sedimentary cover local cataclastic bands lie parallel with bedding. This deformation is interpreted as a décollement between cover and basement.

Also, in the E, an S1 schistosity is found in phyllitic sediments around the isolated granitic cores and is concordant with the granite contact. This foliation also affects the outer part of granitic intrusions.

The S1 schistosity is ubiquitous in Burundi where it is clearly associated with the granitic intrusions : the schistosity and the metamorphic facies of the metasediments both increase towards the granites; moreover, bedding and schistosity in the metasediments are concordant to the contact and the foliation of the granites.

The main characteristic of this subhorizontal S1 foliation is the scarcity of associated folds. Local isoclinal folds are restricted to metaquartzite xenoliths in the granitic intrusions; in places, where the density of granite bodies is important, structures associated with thin-skinned thrusting are present in the vicinity of the granitic intrusions (Fig. 8) Important thrusting is absent in the sedimentary cover where asymmetric folds present a vergence opposed to the underlying thrust direction.

The local thrust structures are not sufficiently abundant to infer the direction of tectonic transport. Indeed, in two places the transport direction deduced from the vergence of the folds on the thrust ramp is seen in opposite directions, at one place towards SE, at the other place towards the W.

Interpretation of the D1 deformation. The D1 deformation appears then as a regional horizontal schistosity with only minor folds, those accom-

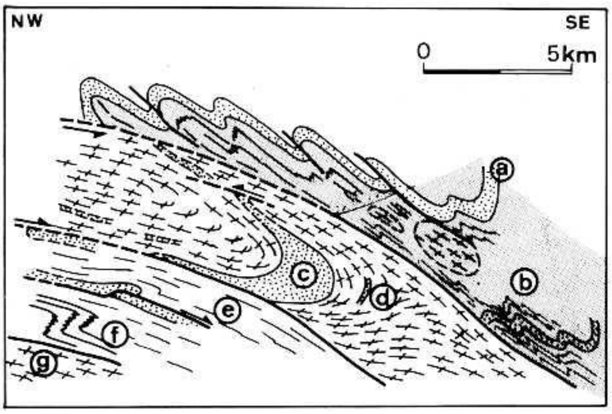

Fig. 8. Thrusting associated with granitoid intrusions. a. Dragfolds in the cover sediments, NW-overturned; b. Isolated granitic intrusions in the cover; c. Remnants of folded metaquartzites in the Gr 2 granites; d. Rests of metasediments in the Gr 2 granites; e. Thin-skinned thrust in a complex of migmatitic gneisses (pre-Kibaran ?) and metaquartzites; f. Recumbent fold; g. Gr 2 granitoids.

panying local thrust structures. Its intensity is spatially linked with the granitic intrusions. In the absence of conclusive information on transport directions, two alternative interpretations are discussed for the origin of the D1 deformation : (1) D1 reflects a regional thrust movement, and the granitic intrusions are emplaced synkinematically with this movement, (2) the D1 deformation is a décollement resulting from early extensional processes; the local thrusting is then connected with the granitic intrusions.

The first explanation implies an entirely compressional type model which considers the cover-basement décollement as a sole thrust. This interpretation also implies that the D1 and D2 deformational phases are contemporaneous : listric thrust faults rising off the décollement surface, steepening, becoming blind and giving way to the upright D2 folds. A major argument against this hypothesis is the age difference between D1 and D2 events obtained from associated granitic intrusions : D1 is dated around 1260-1280 Ma whereas the granites associated with the D2 deformation give ages around 1180 Ma. Both types of granites, either associated with D1 or D2, also are distinctly different in composition.

The second explanation considers that the D1 deformation results form extensional processes. Arguments in support of this hypothesis are the evidence of rifting during Burundian sedimentation and the bimodal nature of extrusive and intrusive magmatic rocks (Klerkx et al. 1984).

In both hypotheses the Gr 2 granites are contemporaneous with the décollement; the increase in the intensity of the foliation and in metamorphic grade near the intrusions is in both cases a result of the synkinematic intrusion of granitic magmas.

The observed isoclinal folds and thin-skinned thrust structures, which are always restricted to the vicinity of granitic intrusions, are not necessarily related to a major thrusting event; they can be explained by the differential movements between parallel intruding granite sheets and intercalated sedimentary sequences. Dragging of the sediments on the granitic sheets or pushing away of the sediments by the intruding granitic bodies may result in local compressive movements which caused local folding or even thrusting.

Evidence for Rifting During Burundian Sedimentation

The junction between the Middle and Upper Burundian sequence corresponds to a transition from mature to immature sediments; the sediments of the Middle Burundian are principally pelites and fine-grained, well sorted quartzites. The Upper Burundian sediments, on the other hand, are arenaceous, coarse-grained, poorly sorted and with angular fragments. The lower part of the Upper Burundian contains conglomerates and subgreywackes rich in fragments derived from the underlying beds, namely fragments of shales. These fragments testify to a phase of erosion prior to, or concomitant with, the deposition of the sediments (Demulder and Theunissen, 1980; Dreesen, 1980). As there is no indication of a phase of folding and erosion before the deposition of the Upper Burundian sediments, it is likely that the erosion of the Middle Burundian shales was due to rifting processes and formation of rift basins in which the Upper Burundian was deposited. These local rift basins possibly correspond to the isolated synclines of Upper Burundian sediments in western Burundi (Fig. 9), whereas a larger basin was formed in the eastern part of the country.

Bimodal Magmatism Related to Extension

Bimodal magmatism is commonly associated with an extensional regime and especially with the development of aulacogens, particularly in the Proterozoic when aulacogens were larger and more frequent (Smith, 1976) : an example is the Athapuscow aulacogen in the Canadian shield (Hoffman, 1973). Bimodal magmatism is also known to be associated with younger extensional regions : the late-Paleozoic plutonic complexes in Morocco are considered to be related to the initial rupture between North America and Africa (Vogel et al. 1976); the association of mafic and acid volcanism during the late Cenozoic of the Western United States is linked to extension (Christiansen and Lipman, 1972); certain parts of modern rift environments are characterized by bimodal magmatism (Barberi et al., 1972; Black et al.,1972; Hart and Walter, 1983).

Igneous activity related to lithospheric extension is considered a result of the intrusion of hot asthenosphere into the continental lithosphere, whatever the process which is ultimately responsible (Sengör and Burke, 1978; Turcotte and Emerman, 1983; Liégeois and Black, 1984). Extrusive magma-

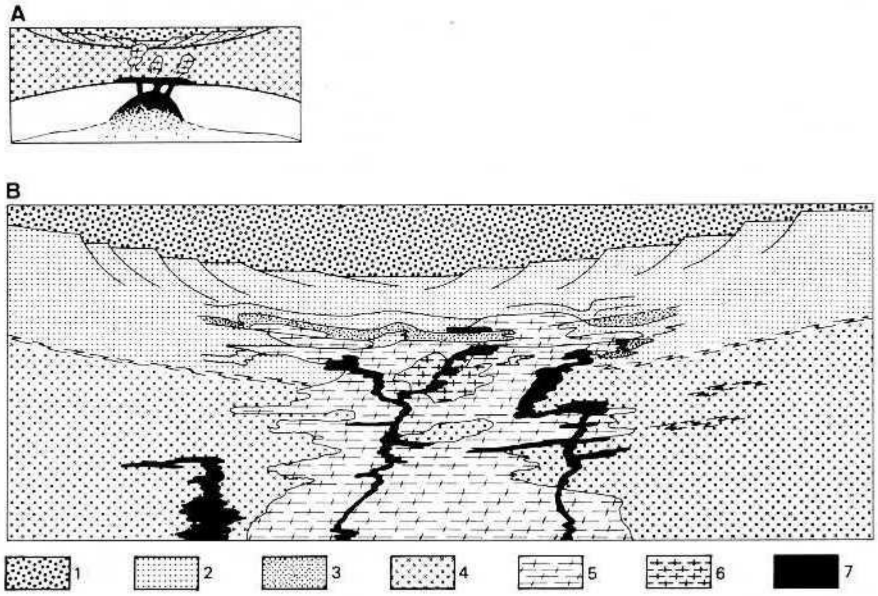

Fig. 9. Section across the Kibaran belt (in Burundi) during the D1 phase (sedimentation, deformation, magmatism): a. At lithospheric scale; b. Across the crustal segment exposed in Burundi. 1. Upper Burundian sediments; 2. Lower and Middle Burundian sediments; 3. Quartzites in 2; 4. Pre-Kibaran basement; 5 and 6. Granitoids intruded during the D1 phase; 7. Mafic magmas intruded during the D1 phase.

tism is not common in the Kibaran belt of Burundi, but there are large amounts of granite and gabbro associated with the D1 phase. Similar bimodal plutonic associations are known in other extensional regions, for example, the late Paleozoic magmatism in Morocco (Vogel et al. 1976). In Morocco, the generation of granitic magmas is considered to have resulted from partial fusion of the lower crust by heat supplied by mafic magmas generated during the extension. Christiansen and McKee (1978) accept a similar process for the origin of the Cenozoic volcanism in the Great Basin of the United States. They propose that the volcanism is connected with thermal effects associated with extension of the continental North American plate. In this region, basaltic magmas generated at different depths within the mantle are intruded in the crust during continuous extension, the heat flow is augmented and rhyolitic magmas are formed in the lower crust by local partial fusion. Hildreth (1981) also considers a primary basaltic source for numerous intermediate and acid magmas. Particularly during a long period of magmatism the intrusion of basaltic magmas is responsible for the partial fusion of crustal rocks so that both acid and mafic magmas will intrude the crust during lithospheric extension.

Although the extrusive igneous activity is limited in the Kibaran belt, it occurs before an intense phase of rifting; this corresponds to an active phase of rifting according to Sengör and Burke (1978), related to thinning of the lithosphere above a mantle plume. This also corresponds to the views of Condie (1982) who classes the Proterozoic supracrustal assemblages according to their lithologies and considers that assemblages of type II (bimodal volcanites - quartzites - arkoses) correspond to aborted mantle-activated rifts.

In the light of the processes outlined above, we can suggest the following origin for the early Kibaran magmatism. The extension was slow and continuous over a long period of time (at least between 1350 and 1260 Ma ago). This slow extension induced negligible fracturing of the crust, thereby reducing the amount of extrusive activity but facilitating the accumulation of mantle-derived magmas at the base of the crust. The accumulation of heat from these mafic magmas caused partial fusion of crustal rocks, thereby generating magmas of granitic composition. The granite generation could be either continuous or limited to more rapid rates of extension. Indeed, the major episode of granitic intrusion seems to be contemporaneous with the climax of deformation related to extension. Although the granitic magmas intruded during this phase of extension in the upper crust have a strong peraluminous, S-type composition, as discussed above, they probably acquired those peraluminous characteristics by contamination in the upper levels of the crust.

Décollement Tectonics Induced By Crustal Extension

The development of a regional horizontal foliation or ductile shear zones as a consequence of

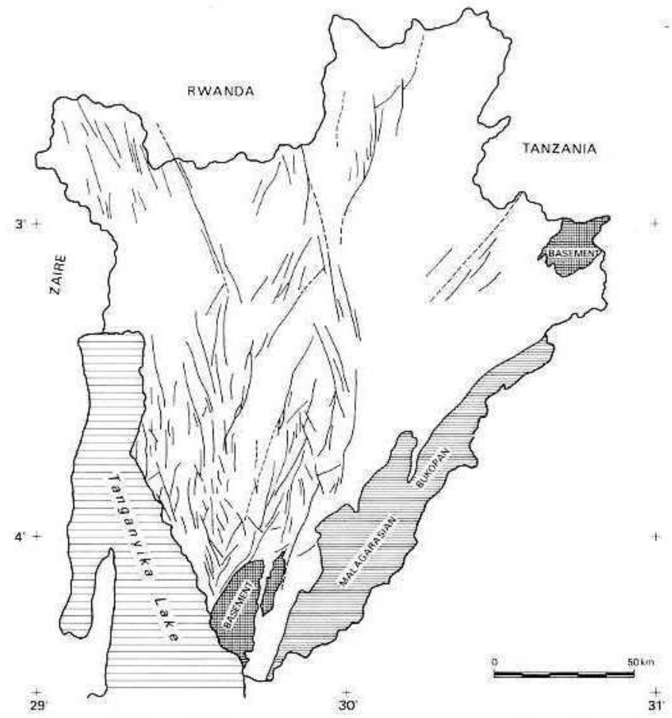

Fig. 10. Distribution of shear zones in Burundi.

crustal extension has been proposed by Oxburgh (1982). As exemplified by the Bay of Biscay (Montadert et al. 1979), the upper part of the crust is thinned by movement along listric faults, whereas the lower part, beneath about 8 km, is deformed by homogeneous and ductile stretching. Considering that the total thickness of the Burundian sediments is between 11 and 14 km, the zone where the granites are intruded and where the D1 structures develop lies in the zone of ductile behaviour. In this zone the extension results in the formation of localized horizontal shear zones, the deep level expression of listric faults; these sites may correspond to localized more intense zones of foliation in the lower Burundian metasediments. Along these horizontal listric faults, the highly fluid granitic magmas could easily intrude the metasediments. The high fluid content, which results in a high fluidity of the magmas, is manifested by the high proportion of hydrated minerals in the granites, their ability to assimilate sedimentary rocks and their high tourmaline content.

The synkinematic emplacement of the granites, intruding the sediments or as elongated bodies, sometimes even as sheets parallel to the décollement zone, was able to create local zones of compression and thrusting. Indeed, the intrusion of highly fluidy magmas can disequilibrate the sedimentary pile and induce differential movements between the granites and the metasediments which are of different competence.

It is possible that the process of extension has been accelerated at the time when the rift basins of the Upper Burundian were formed; these rifts may be the compensation in the upper part of the crust for the extensional movements which, in a lower part, are compensated by introduction of a greater amount of granitic magmas, under a thickness of 8 to 10 km of sediments which were already deposited at that time.

Compressive Tectonics During a Later Deformation Phase (D2) and D2-Associated Magmatism

The D2 Deformation

The deformation responsible for the morphologica signature of the belt produced open upright folds, mostly oriented NE-SW in the investigated area, but which, on a regional scale, swing from a NE-SW direction in the southern part of the Kibaran segment (Shaba, Burundi) towards a NW-SE direction in the northern part (Rwanda, Uganda). This phase of open folding did not result in significant crustal shortening. Although a cleavage is axial planar to the folds, the structures resulting from the D1 deformation and associated magmatism are only partly obliterated by the D2 event.

Granitic intrusions, associated with this phase of deformation, occur in the cores of anticlines and consist of two-mica granites. They are typically intrusive, homogeneous in composition and are not usually foliated; these features distinguish them from the Gr 2 granites. These late intrusions have different compositions (compare Fig. 4 and 6) and also have more typical crustal signature ($^{87}Sr/^{86}Sr$ initial ratio of 0.733). Their Rb-Sr age of 1185 ± 59 Ma (Klerkx et al., 1984, see Fig. 7a) may be considered to correspond to the age of D2 deformation, as the granites typically occur in the cores of D2 anticlines.

The D2' Shearing Event and Associated Magmatism

The latest Kibaran structural event to affect the region is a shear event, corresponding to the development of shear zones along two conjugated directions, NE and NW (Fig. 9 and 10), which are parallel to both directions of compressive D2 deformation. All the older structures are overprinted by a strongly developed set of NNE and NNW oriented shear zones. They appear as local zones of intense deformation (Fig. 9), characterized by a pervasive cleavage with an increasing intensity towards the centre of the zone. The sedimentary strata generally show moderate to intense folding at the margin of the zones. The centre of the zones consists of cataclastic or even mylonitic rocks. The quartzites in particular show gently plunging or even horizontal stretching and mineral lineations. These shear zones are considered to have behaved as strike-slip zones.

Concerning the sense of displacement along these shear zones, dextral as well as sinistral movements have been observed with a predominance of dextral displacement. Intrusions of alkaline granites

TABLE 2. Chronological Sequence of Tectonic Events in the Kibaran Belt and Associated Magmatism

Date	Tectonic Event	Phase of Deformation	
950 ~ 1000 Ma	Post-tectonic granites (Sn-bearing)		
1100 Ma	Sub Alkaline granites Ultramafic and mafic intrusions	D2' shear	COMPRESSION
1200 Ma	Granitic magmatism	D2 deformation Open, upright, cylindrical folds	
1250 Ma ↑ 1330 Ma	Granitic and associated mafic magmatism	D1 deformation extensional structures (locally thin skinned thrust in granitic environment)	EXTENSION
1350~1400 Ma	Acid volcanism	Formation of sedimentary basin	

(Tack and De Paepe, 1983; Tack, 1984) are spatially associated with the NE-SW shear direction.

Preliminary age determinations have been performed by the Rb-Sr method on these alkaline intrusions. A preliminary isochron on the Makebuko massif gives an age of 1068 ± 78 Ma (6 whole-rock samples) Ro = 0.7109 ± 0.0044; MSWD = 0.9) (Fig. 7b, Table 1). If two samples of the Bukerasazi pluton, which is a satellite pluton of the Makebuko massif, are added, an age of 1125 ± 25 Ma is obtained (Ro = 0.7077 ± 0.0021, MSWD = 2.0).

The age of the D2' shear is inferred from both the age of the alkaline intrusions which are emplaced around 1100 Ma and which are spacially associated with the shear zones, and from the result, although imprecise, of a provisional Rb-Sr age determination on mylonites from the NE shear zone: 1095 ± 111 Ma (Ro = 0.756 ± 0.022; MSWD = 0.05).

As the alkaline intrusions of Makebuko and Bukerasazi are themselves locally sheared, the maximum age for the shearing event along the NE-SW direction is about 1100 Ma. Moreover, the relatively low $^{87}Sr/^{86}Sr$ initial ratio indicates a deep origin for the alkaline plutons which gives a lithospheric scale to the D2' shear.

More problematic is the significance of the mafic and ultramafic intrusions which, in Burundi, are also aligned NE, parallel both to the major D2 folding direction and to D2' shears. They are part of an important alignment of ultramafic bodies which extends northwards to Lake Victoria in northern Tanzania. These intrusions have also been formerly connected with the shearing event (Klerkx, 1984). However, an age indication (work in progess) suggests that they are older and possibly are contemporaneous with the D2 folding phase. They consist of huge bodies of peridotite with or without associated gabbro, norite and leuconorite. They show clear evidence of intrusions into the Burundian sediments (intrusive contacts, contact metamorphism, deformation of the sediments at the contact). Although these complexes have been only superficially studied, the gabbroic-noritic rocks show evidence of being layered intrusions. The internal structures of the ultramafic rocks, however, e.g. alternating layers of peridotite and

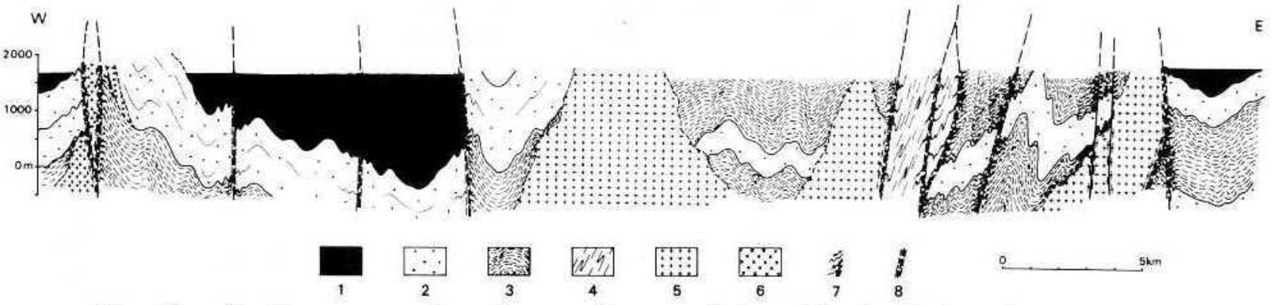

Fig. 11. Section across sheared zones in central Burundi. 1. Shales; 2. Quartzites; 3. Sandy shales; 4. Sheared rocks; 5. Granitoids; 6. Mafic rocks; 7. Shear folds; 8. Shear faults.

norite, suggest that they have been emplaced as a crystal mush of olivine crystals in a noritic liquid matrix. The mafic intrusions may be considered as derivatives of the ultramafic crystal-liquid mixture.

The processes responsible for the generation of these magmas in the mantle and for their intrusion into the upper crust remain to be studied. Although there is an age difference between the early Kibaran bimodal magmatism that is contemporaneous with the D1 deformation, and the emplacement of the mafic-ultramafic bodies, it may be reasonable to accept that these magmas still belong to the mafic magmatism generated during the early phase of extension.

So called post-tectonic granites in the Kibaran belt have been known for a long time. They are associated with dykes and pegmatites with cassiterite, columbo-tantalite and wolframite mineralisation. They are found mainly in Shaba and in Rwanda and have been dated at about 970-990 Ma (Cahen et al. 1979; Lavreau and Liégeois, 1982). They have typical crustal characteristics, but their genetic significance is not well understood. However, they do not belong to the Kibaran orogeny as these granites cut Pan African Katangan sediments in the Itombwe syncline in Kivu, Zaire (Cahen et al. 1979).

The Northern Kibaran Segment as Part of Kibaran Age Events in Eastern and Southern Africa

Considering the Burundi region to be representative of the northern segment of the Kibaran belt - the Kibaran belt sensu stricto, extending over Shaba, Burundi, NW Tanzania, Rwanda and SW Uganda -, we may infer that the formation of a basin in this area started around 1400 Ma ago and was followed, around 1350 Ma ago by bimodal magmatism, comprising large intrusions of granitoids. This magmatism persisted until 1260 Ma, occurring contemporaneously with a pervasive horizontal deformation, resulting from the décollement of the sedimentary cover over its basement. Décollement and associated magmatism are seen to be related to a process of lithospheric extension rather than to compressive tectonics, and occurred entirely in a intracontinental environment without evidence of crustal rupture. The main structural and magmatic characteristics of the belt were acquired during this phase that ended around 1260 Ma ago.

Subsequent compression, resulting in upright folding (ca. 1180 Ma) and, finally, shearing around 1100 Ma ago have not dramatically modified the earlier features. The significance of D2 folding and particularly of the shearing event will now be discussed in relation to the large scale events which occurred in Kibaran times in the eastern and southern African subcontinent.

The Kibaran belt sensu stricto evolved independently from other subsynchronous, parallel belts in south-eastern Africa. The Kibaran belt s.s. is separated from other Kibaran domains situated more S by the Bangweulu block in Zambia of Lower Proterozoic age, and by the Tanzanian Archaean craton. The two other main belts of Kibaran age are the Irumide belt to the SE and the Malawi-Moçambique belt still farther to the SE. The Irumide belt is mainly composed of supracrustal rocks and presents some analogies with the northern Kibaran segment. It has been quoted previously as an intracratonic mobile belt (Shackleton, 1969; Hurley, 1973; Watson, 1976). Recently, however, Daly (1985), with convincing arguments, has interpreted the Irumide belt as the NW-facing foreland fold and thrust belt of the southern Moçambique belt. As the structural evolution of the Irumide belt is much more complex than the northern Kibaran belt, it is not easy to characterize its early development. Nevertheless, the rock sequences and the magmatism are very similar to the northern Kibaran belt. It is thus possible that the Irumide basin evolved by extensional processes in an early stage of its evolution, before involvment in the collision processes which occurred in the Malawi-Moçambique belt. Various authors (Andreoli, 1983; Jourde, 1983; Sacchi, 1983; Daly, 1985) presented arguments for interpreting the orogeny in Moçambique and Malawi in terms of NW-dipping subduction, collision tectonics and accretion.

Ages of about 1100 Ma are reported both for the Irumide belt and for the higher grade Malawi-Moçambique belt. This implies that the younger compressive tectonic events in the northern Kibaran belt

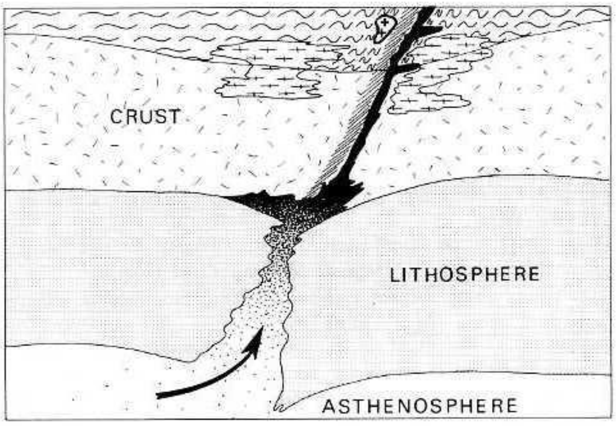

Fig. 12. Strike-slip resulting from delamination of the lithosphere; shear zones develop along the strike-slip zone with associated mafic and ultramafic intrusions as well as alkaline intrusions.

are contemporaneous with continental collision and accretion invoked in the southeastern belts.

Daly (1985) has also proposed that the Irumide belt is interrupted at its north eastern margin by a NW-SE directed transform fault to which he assigned a Kibaran age. This transform zone reaffects NW-SE oriented structures of Ubendian age (Lower Proterozoic), the Ubendian belt having been interpreted recently (Daly et al. 1985) as a lateral accretion belt to the Archaean Tanzania craton. The late shearing which occurs in Burundi along a conjugate set of directions, NW-SE and NE-SW, could be considered as a continuation to the north of this Irumide transform zone.

It consequently appears that the compressional tectonics observed in Burundi (from D2 at 1180 Ma to D2' at 1100 Ma) can be attributed to the NW subduction and final collision which may have occurred in the southern Malawi-Moçambique area.

As alkaline intrusions are associated with this shearing, this event can be considered as a major event which has affected the entire lithosphere and may be the result of lithospheric delamination (Kröner, 1983) (Fig. 12). Recent studies favour lithospheric control for alkaline magma genesis (Black et al. 1985). The ultramafic magmas could also be considered the result of the melting of hot asthenosphere injected into the lithosphere.

Conclusions

The northern Kibaran belt, investigated in Burundi, is an example of a linear intracontinental belt which is considered to have originated by a process of crustal extension. Sedimentation began about 1400 Ma ago. A a result of crustal thinning intensive bimodal magmatism - granitic and gabbroic - affected the upper crustal sediments during a period between 1350 and 1280 Ma ago. The extensional tectonics resulted in a décollement of the sedimentary pile over its basement and in widespread horizontal deformation of the lower sedimentary sequence; this deformation occurred contemporaneously with the intrusion of granitic magmas. The generation of granitic magmas is considered to have result from the fusion of lower crustal rocks by heat transfer from the mafic magmas which intruded the base of the crust during the extensional processes (Fig. 11).

Most of the features which result from the extension have been preserved during later compressive tectonics. The latter culminated around 1180 Ma ago with upright deformation and ended around 1100 Ma ago during a major shearing event. Alkaline granitic intrusions and probably also mafic and ultramafic complexes were intruded along the shear zones which may be related to delamination of the subcrustal mantle lithosphere.

It consequently appears that time relations and structures of the compressional stages in the northern Kibaran belt closely match those in the southern Malawi-Moçambique belt where collision probably occurred. The compressive tectonic phase in the northern segment is considered a product of that collision. The northern Kibaran basin, however, developed initially completely independently of processes in the southern area. It behaved as an aborted rift basin, evolving entirely in intracontinental conditions, whereas continental separation and ocean formation was active in the southern Malawi-Moçambique region.

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