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The Itombwe belt (Kivu, RD. Congo): A Far-Field Effect of Eastern Pan-African Belts on the Neoproterozoic Rift, in Central Africa

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Abstract
The Itombwe belt is a North-South oriented structure which belongs to the Neoproterozoic rift system of central Africa including at least four troughs folded during the Pan-African orogeny. This Neoproterozoic rift located inside the Congo craton is tectonically dependent of the far away (400 to 800 km) Pan-African belts surrounding the Congo Craton. The N-S opening of this Itombwe structure around 662 Ma and its folding by 550 Ma is linked to the eastern Pan-African Mozambique belt rather than the Southern Lufilian one (Katanga). This study includes geological observations from the thin section to the regional scale deformations. The model could be compared to similar regional rift systems such as the Tertiary Mid-European and the East African rifts. An overall geodynamic explanation based on field studies and radiometric data is proposed. This explanation takes into account the tectonic transfers along the transcurrent fault zones as a major cause of folding far away from the pan-African belts

Keywords: Itombwe trough, Neoproterozoic rift, Pan-African belts, geodynamic model, Kivu, RD. Congo, Central Africa, East Africa

Introduction

This study focussing on the Itombwe belt in the eastern part of the democratic republic of Congo aims to link the Neoproterozoic rift located in the Congo craton and particularly the Itombwe basin which is a master piece of this "Neoproterozoic rift" (Figure.1) to the coevals surrounding "Pan-African" belts such as the central Africa copperbelt Lufilian and Zambian belts to the South and the Mozambique and Madagascar belts to the East. The evidence of a "Neoproterozoic rift" is new although some structures related to this rifting were evidenced since long time (1969 and 1973) particularly in the northern "Luma and Loyo" (Congo) and "Bunyoro" (Uganda) belts. But with the progress of field observations and radiometric data, the enigmatic "Itombwe belt" allows us to evidence a Neoproterozoic rift, similar to the present EARS, but located in the southern part of this African area. However, the evidence for the ascribing this Itombwe to the Neoproterozoic has taken a long time (since 1979-1980) and allows comparing the Neoproterozoic rift to its present analogs. Such data are exposed below in part 4. The Pan-African orogen which succeeded to the Kibaran orogen and led to the assembly of Western Gondwana between 950 and 500 Ma suffered several tectonothermal events which have impacted this Neoproterozoic rift. Geochronological and geological data show that this ancient rift and surrounding belts are strongly dependent. Tectonic constraints were transmitted to the rift structures and surroundings basement both by local folding and large transversal transcurrent shear-zone.

Geological Framework

The Congo Craton (CC) at the end of the Mesoproterozoic, gathered the Congo Block (CB), the Tanzania Block and the Bangweulu Block (BB) reunited by the Kibaran belts (Figure.1)

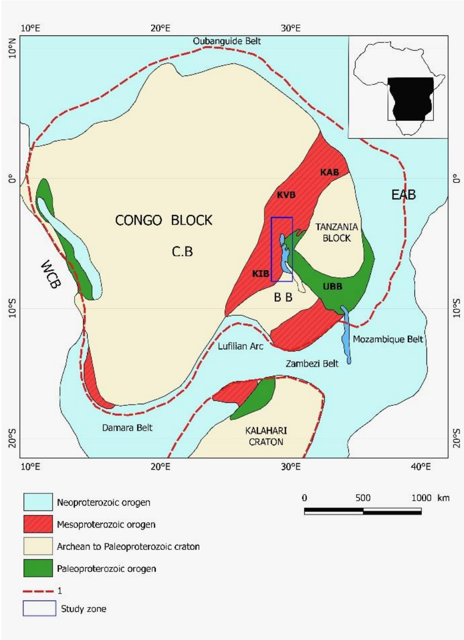

Figure 1: The Congo Craton (CC) and Pan-African Belts After Villeneuve et al. [1]. Modified. Legend: CB-Congo Block, BB-Bangwelu Block, WCB-West Congo Belt, EAB-East African Belts, KAB-Karagwe-Ankolean Belt, KVB- Kivu Belt, KIB- Kibarides, UBB-Ubendian Belt

It is surrounded by several Pan-African belts and particularly the Mozambique belt to the South East and Zambian and Lufilian belts to the south. However, inside the CC, between the Congo and Tanzanian blocks, several structures linked to the Pan-African belts crops out within the Mesoproterozoic Kibaran belt, close to the present African rift and alongside the great eastern African lakes. These internal structures constitute the Neoproterozoic rift which is the topic of the present paper. These structures constitute the new called "Central African Neoproterozoic rift". The Geology of this Central Africa area can be divided in two parts: the basement (Archean to Mesoproterozoic) and the post-Mesoproterozoic events including three different geological events: I-the Panafrican orogen, including the cambered zone with anorogenic complex, the Neoproterozoic rifting with opening and closure of throughs, II-the Karoo event with deposition of the carboniferous tillites and associated Permian and Triassic deposits, III- the East African rift with its associated volcanic outpouring (Tertiary to Quaternary). These post-Kibaran events are exposed in Figure. 2. Our study is only devoted to the Pan-African orogen.

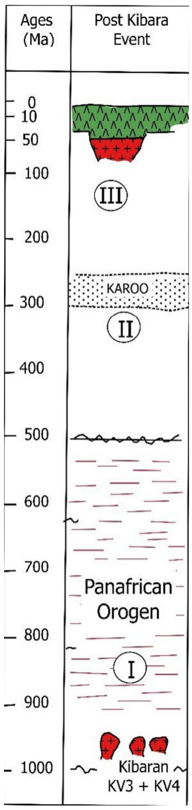

Figure 2: The Main Post-Kibaran Events in Central Africa

Legend: I- Pan-African Orogen, II- Karoo deposits, III-East African Rift: Sediments and Lavas. KV3 and KV4 are the Last Stages of the Kibaran Orogeny in Central Africa [2].

The basement of this central African area is mainly composed by the Kibara belts recently synthesized by and [2,3]. According to the Kibaran orogen includes five different stages (K1 to K5) between 1600 and 950 Ma [2]. Older units belonging to the Archean or Paleoproterozoic are the Kibalian (northeastern DR Congo), the Ruzizian (Southern Kivu and Rwanda and Burundi) and the Tanzanian basement (Tanzania, Kenya and Uganda). The younger Kibaran stage (1100 to 950 Ma) corresponds to the post tectonic granitic intrusions (G4 granites) which provide the main occurrences of Tin and Coltan minerals. By contrast, the post-Kibaran events except the modern rift and associated deposits are less known. The topic of this paper is to enhance our knowledge on the post Kibaran events between the last intrusive Kibaran stage (1000 -950 Ma) and the last Pan-African tectonic events (550-500Ma). On the contrary to the surrounding areas exhibiting large belts linked to the plate tectonic orogens (Mozambique, Madagascar and Lufilian belts), our studied zone only presents rare structures coming from an ancient rift and folded by a field effect of the surrounding belts. This Neoproterozoic rift corresponds to several troughs infilled during the late Neoproterozoic and folded at the end of the Neoproterozoic and the beginning of Cambrian, during the last Panafrican stages. Between the surrounding Pan-African belts and the Neoproterozoic rift structures, some of the Kibaran belts are locally remobilized by tectonic or metamorphic effects but also along the transverse faults which play an important role in the tectonic transfers from the Pan-African belts to the central rift structures. This Pan-African orogen which took place after the Kibaran orogeny is bracketed between 950 and 500 Ma.

The Neoproterozoic Rift System in Central Africa

The Neoproterozoic deposits in central Africa consist in two main assemblages: The Central rift (blue in Figure.3) close to the great lakes and the flat sedimentary covers on both sides of this Lakes area with the Lindian to the west and the Malagarasian (and Bukoban) to the east.

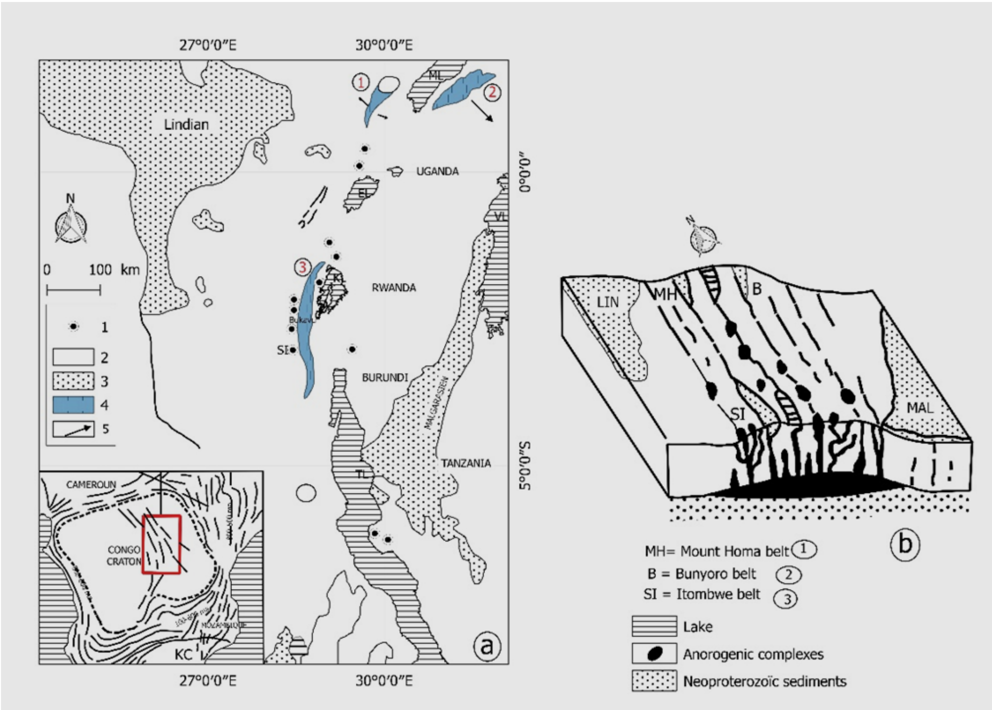

Figure 3: The Neoproterozoic Rifting in central Africa. Figure 3a: The Main Belts Linked to the Neoproterozoic Rift, 1- Mont Homa, 2-Bunyoro, 3-Itombwe

Legend: 1- Anorogenic intrusions, 2-basement, 3- Neoproterozoic covers, 4- Troughs and belts linked to the Neoproterozoic rift, 5- Fold "vergence" in the Neoproterozoic belts. Figure.3b: 3D interpretation of the Neoproterozoic rift system. LIN-Lindian sediments and MAL- Malagarasian sediments.

The Neoproterozoic Rift

The Neoproterozoic rifting consists in several elongated N-S structures setting in the vicinity of the Great African Lakes similarly to the present Eastern African rift and numerous anorogenic intrusions geographically associated (Figure.3). This similarity between the Neoproterozoic rift and the present East African rift has been underlined by several authors following Dixey. According to Villeneuve the main structures ascribed to this Neoproterozoic rift are: the Itombwe belt the Irumu belt and the Bunyoro belt [4-17]. However, other outcrops with tillitic formations (Haute Ibina, Gety, etc.) have been associated to this Neoproterozoic rifting. The Itombwe (3 in Figure.3) will be developed in the next part, but the associated belts: Irumu (1 in Figure.3) and Bunyoro (2 in Figure 3) have been evidenced since 1969. The Irumu structure consist in three different units with the folded Luma and Loyo formations at the base and the flat lying Mount Homa and Lukuga formation on top. The basal formations are very similar to those of the Itombwe belt, the mid horizontal Mount Homa is linked to the upper part of the Lindien deposits and the Lukugafm is linked to the carboniferous glacial event. The Bunyoro structure in Uganda includes three folded formations: a conglomeratic formation to the base, an argilitic formation in the middle and a tillitic formation to the top. The relationships between the flat covers and the Neoproterozic rift formation are still in debate but five stage of development have been evidenced from the end of the Kibaran orogen (950 Ma) to the end of the Panafrican orogen (500 Ma): P1 (950-850 Ma), P2- (850-700 Ma), P3- (650- 620 Ma), P4 (620-550 Ma) and P5 (550-500Ma). Concerning the Neoproterozoic rift, three periods are considered: ante-rifting, rifting and post rifting.

Ante Rifting (stages P1 and P2)

Stage P1 corresponds to the deposition of the Mwasha (Roan group) and stage P2 to a cambered zone parallel to the Great Eastern African Lakes zone followed by a period of E-W extension giving rise to anorogenic intrusions (Figure.3). These anorogenic intrusions (granites, syenites and carbonatites) occurred between 800 Ma and 700 Ma (Table I). Younger than the post Kibaran tectonic granites, there are thirteen alkaline and carbonatitic complexes mainly located on the western Kivu Lake shoreline. Three types of intrusive complexes have been evidenced by Kampunzu et al.: 1-Undersatured silicate rocks and carbonatites (Bingo, Lueshe, Kirumba and Numbi); 2- Oversatured and undersatured with carbonatites (Upper Ruvubu complex in Burundi) and (3) Silica-oversatured rocks (Kahuzi and Biega massifs). Table 1 provides some radiometric ages from seven anorogenic intrusions. However, ages are provided by different methods: U-Pb on zircons and Rb/Sr on whole rocks [18].

Location	Methods	Data	References
Lueshe	Rb/Sr	822+/-120 Ma	[18]
Lueshe	U/Pb	798.5 +/-4.9 Ma	[19]
Kirumba	Rb/Sr	803+/-22 Ma	[18]
Numbi	Rb/Sr	830+ /-51 Ma	[18]
Kobokobo	U/Pb sur Beryl	900 Ma	[20]
Kahuzi 1	U/Pb	825 +/-5Ma	[21], [34]
Kahuzi 2	U/Pb	814+/-5	[34]
Matongo/Hte Ruvubu	U/Pb	705+/- 4.5 Ma	[19]
Matongo/Hte Ruvubu	U /Pb and Rb/Sr wr	740+/- 7 Ma	[22]
Kambuzi	Rb/Sr Wr	542+ /- 27 Ma	[23]

Table 1: Radiometric Data on the Anorogenic Complex Around the Itombwe Belt

These radiometric ages are in the bracket from 850 to 705 Ma and correspond to the age of detrital zircons recorded in the Nya-Ngezie formations belonging to the basement of the Itombwe structure . These detrital zircons have been ascribed to the surrounding anorogenic complexes [2].

Rifting

The rifting stage corresponds to the opening of the troughs according to the age of the first deposits. However, without fossils and chronological data, this age of deposits is confusing and depends of correlations with adjacent areas. The stratigraphic sequence in the Irumu through (half graben) start with green sericitoshists (Luma fm) covered by a succession of sandstones, shale and tillitic levels (Loyo fm). These two formations, folded and slightly metamorphosed are capped by the flat Mt Homa formation with dolomites, shales and conglomerate covered by the Lukuga formation belonging to the Karoo system (Permian and Trias). The tillitic levels have been correlated with the Akwokwo setting at the base of Lindian (950 Ma) by Sluys [14] and Lepersonne [15]. The only one known at that time, but these glacial sediments with their surrounding equivalents (Gety tillite, Mont Nongo and Eholu conglomerates) could also be correlated with the Marinoan glacial event (650-635 Ma) now well-known over the Africa. The symmetrical Bunyoro series evidenced by Davies were studied by Bjorlykke [16,17]. These series also folded are composed of shales and tillitic levels with "drop stones' deposited between 650 Ma and the beginning of Cambrian [17]. We notice that vergences of thrusts in the Irumu and Bunyoro belt are opposite.

Post-Rifting

Taking into account that these intra-rift deposits are folded and slightly metamorphosed, the post-rift period is obviously linked to the age of this tectono-metamorphic event ascribed to the last Pan-African events. But the true ages of these events are not known due to the lack of relevant geochronological data. However, the datations on the Itombwe structure bring these informations.

The Lindian and Malagarasian-Bukoban Flat Covers

The Lindian in northern DRC and the Malagarasien-Bukoban in Burundi, Rwanda and Tanzania. The Lindian studied by Verbeek consist in 2500m of sediments with a lower Ituri group (200m) ascribed to the Kibaran deposits and an upper part starting with a tillitic level ascribed to the Akwokwo tillite (950Ma) until the end of the Aruwimi formation (620

Ma). Correlations with the Ubangien of RCA favor a more recent glacial event (Sturtian?) for the Akwokwo tillite. Parts of this little deformed cover has been evidenced in the folded belt of the Neoproterozoic rift (Luma and Loyo fm). The Malagarasian (in Burundi) and The Bukoban (Tanzania to Uganda) consist in 1700m of sediments. Radiometric data by K-Ar and Ar-Ar methods (on minerals (plagioclase, clinopyroxenes, biotite and hornblende) on intruded dolerites yield two groups different of ages: 1300 to 1200 Ma and around 795+/-7 Ma. These results favor the distinction in two different covers: The lower ascribed to the Mesoproterozoic margin of the Kibaran belt on and the upper to the Neoproterozoic deposits [24-26].

The Itombwe belt

History

The southern part of the Itombwe syncline was evidenced since 1946 [27]. At Luemba (South Kivu) by a disconformity but it was ascribed to the upper Burundian (Late Mesoproterozoic). Later on, this disconformity was evidenced close to Bukavu by Villeneuve [6,7]. But ascribing it to Neoproterozoic was done later on [10,11,28,29]. New geochronological data allow us to date its opening and closure [3,13,29].

Structure

The main geological study devoted the Itombwe belt is exposed in and interpreted in Figure.4. According to Figure 4, the Itombwe structure is a N-S elongated belt which extends from the North of the Tanganyika Lake to the north of the Kivu Lake with only 20 km of width (Figure.4a). Figure 4b exposes an E-W cross section which is interpreted in Figure 4c as a graben with an active normal fault to the west [10].

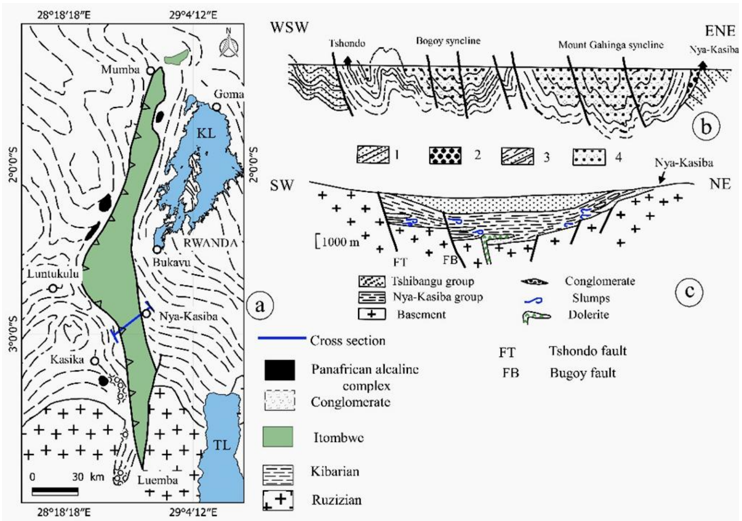

Figure 4: Geology of the Itombwe Belt Consistency: 4a- Sketch Map of the Itombwe Belt With Location of the Profile Tshondo-Nya-Kasiba, 4b-Cross-Section Tshondo-Nya-Kasiba, 4c -Interpretation of the Itombwe Trough Infilling

Legend: Figure.4b- 1-Kibaran basement, 2-Nya-Kasiba conglomerate, 3-Nya-Kasiba formation (shales and sandstones), 4- Tshibangu formation (mixtites and shales) The main studied zone was along a cross section between Nya-Kasiba and Kasika located in Figure. 4a and presented in Figure.5. (ABC profile)

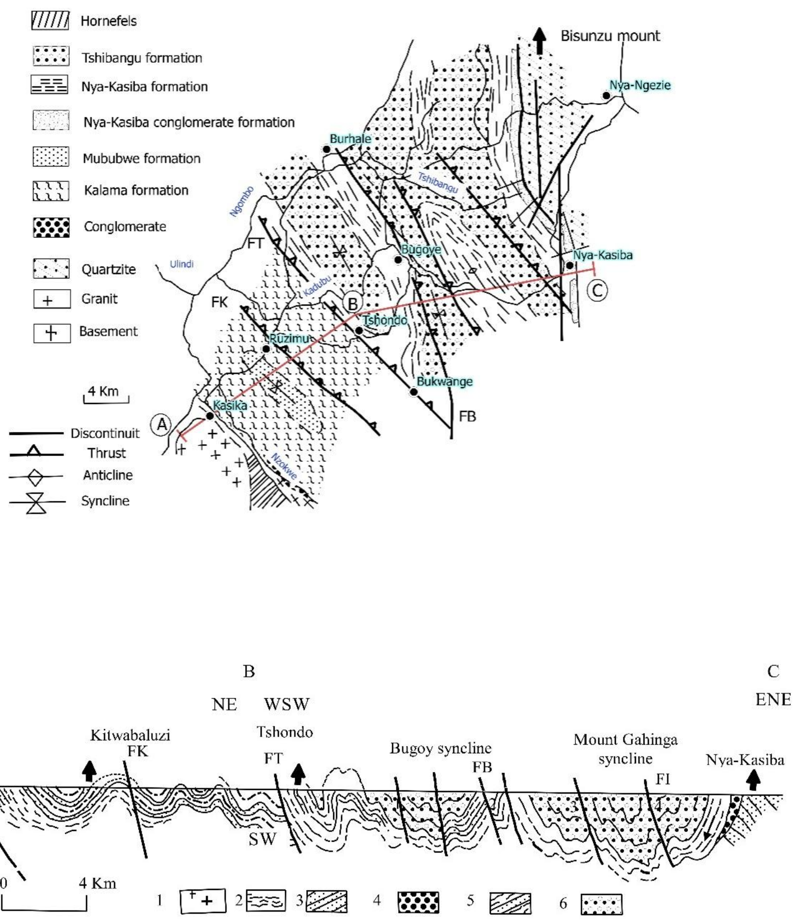

Figure 5. Geology of the Central Part of the Itombwe Belt. 5a- Geological Sketch Map of the Area Between Kasika and Nya-Kasiba. Two Different Terranes Have Been Distinguished: A Western Group (A-B section) Belonging to the Burundian and an Eastern Group (BC section) Belonging to the Neoproterozoic Itombwe Belt. 5b- Geological Cross-Section Along the A-B-C Profile, Between Kasika and Nya-Kasiba

Legend- 1-basement, 2- gneiss, 3-quartzites and schists, 4-basal conglomerates, 5- shales, 6- mixtites.

Although thes terranes are parallel their contain is very different. The western group is more metamorphic and the eastern group only contain a tillitic formation. The Western part sufferred two tectonic events meanwhile in the Eastern part, only one is evidenced. Both are separated by the Tshondo Fault zone (FT) interpreted in Figure.4 as a normal fault. The eastern limit of the Itombwe is the Ny-Kasiba unconformity underlined by the Nya-Kasiba conglomerate. Later on, 9 other geological sections (3 to the south of the Kasia-Nya Kasiba cross section and 6 to the North of this cross-section) have completed this Itombwe structure.

Evolution

The evolution of the Belt and consist of three different stages: I-pre-opening, II-opening and infilling and III-closure of the graben by folding of sediments.

Pre-Opening

The occurrence of several anorogenic intrusions on both sides of this Itombwe belts which are dated between 820 and 705 Ma. (Table I) could be linked to above-mentioned cycle P2.

Opening and Infilling

The stratigraphic succession (Figure. 6) shows two superimposed formations: Nya-Kasiba to the base and Tshibangu on top.

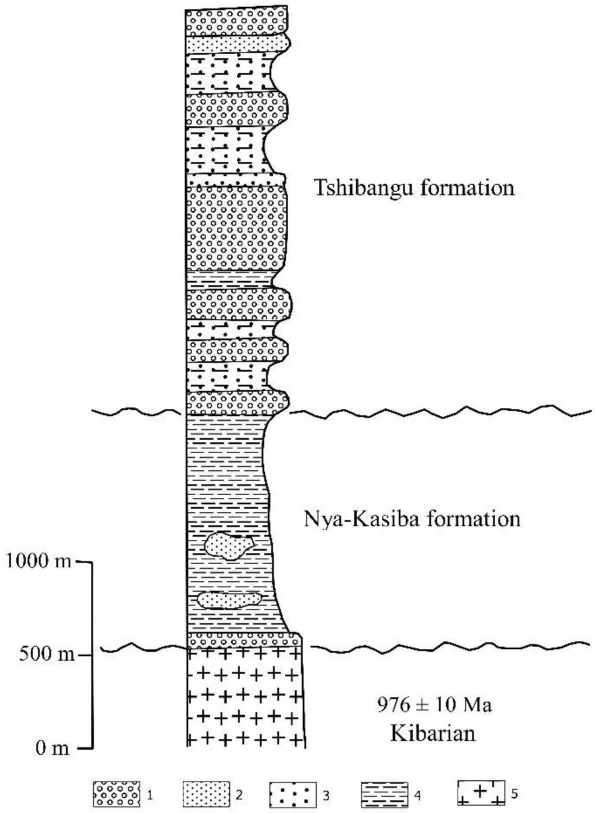

Figure 6: Sedimentary Succession in the Itombwe Belt

Legend: 1- Conglomerates, 2- Sandstones, 3-Mixtites (tillites), 4- shales, 5- Kibarian basement

The Nya-Kasiba formation consists of shales with a conglomerate at the base and the Tshibangu formation includes a succession of black shales interbedded with tillitic layers. The presence of clasts of tin granites (1-0.95 Ma) in the basal conglomerate allow us to establish the post Mesoproterozoic age of this basin. But, 36 detrital zircons from the basal conglomerate of the Nya-Kasiba formation have been dated by U-Pb by Kampunzu et al., [29]. In the sample IT657. This sample provides ages in the range 777- 662 Ma and a weighted mean age at 707+/-10 Ma (U-Pb on zircons). The maximum depositional age in this basal conglomerate is less than 662 Ma.

Sample	Location	Methods	Datations	References
IT 657	Itombwe belt	U/Pb on zircons (SHRIMP)	Weigthed mean age : 707+/-10 Ma	Kampunzu et al. (2003) Unpublished

Table 2: U-Pb Ages From The Basal Conglomerate of the Nya-Kasiba Formation (Itombwe Super group) [29]

A minimal age for deposition is given by the Ar/Ar ages of hydrothermal muscovites from the Twangiza pyrite – arsenopyrite bearing ore deposits yielding ages between 629+/-7 and 608+/-9 Ma [33]. Other clusters of ages on detrital zircons have been recorded in this IT657 sample: 2700-2600, 2000-1900, 1200-900,800-650 Ma which corresponds to the ages of the basement. Similar age clusters have been evidenced in the Nya-Ngezie group which is the basement of the Itombwe structure, with exception for the group 800-650 Ma. This favours a local provenance for the zircons dated in sample IT657 [2,29]. However, the lack of detrital zircons in the range 900-800 Ma is noteworthy. This gap corresponds to a magmatic gap in the country. Thus, the opening post 662 Ma could explain the lack of Sturtian glacial (717-660 Ma) deposits and the deposition of Marinhoan glacial (650-635 Ma) sediments (Itombwe tillite).

Closure and Folding

Taking into account that there is no local plate tectonic event, the closure and folding of these Neoproterozoic to early Cambrian structures is linked to the Pan-African orogeny that occurred around the central African Craton, in surrounding Pan-African belts. Pan-African ages are also recorded in the Archean or Kibarian basement. These Pan-African deformations are well studied both in the Itombwe trough and in the eastern neighbouring basement.

In The Itombwe Trough

The tectonic imprint, in the Itombwe structure, is evidenced by the dip of the stratification and by a vertical shistosity. However, some isoclinal folds are observed at different scales: at a regional scale (Figure.4b) and on hand samples (Figure. 7a). The shistosity is parallel to the fold axial plane (Figure.7b) and is materialised by biotites (Figure 7c). The orientation of the axial plane of folds and shistosity are mainly N-S to WSW-ENE. No reworking of this fold have been observed in the Itombwe formations indicating that those folding phases is the last one in this central Africa area.

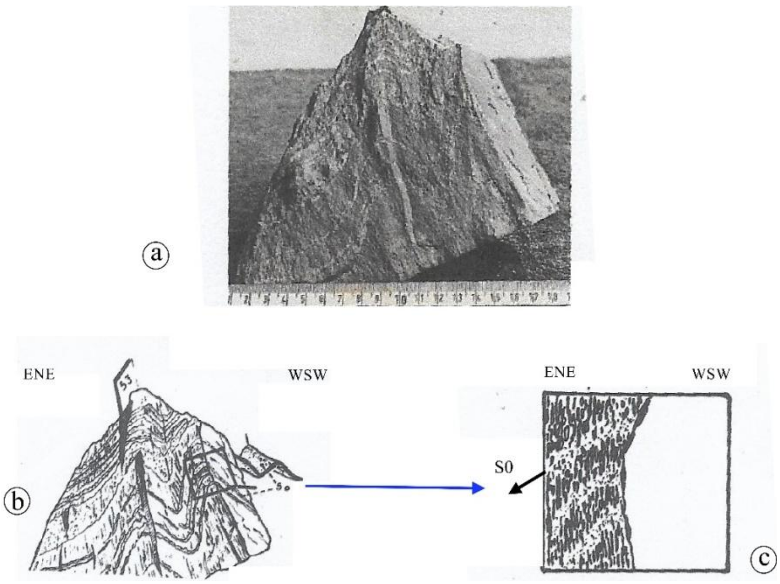

Figure 7: Fold of the Itombwe Belt at Centimeter Scale; a: Photograph of a Centimeter Fold, b-Interpretation of the Centimeter Fold, c- Thin – Section With Biotites Recristallized Along the Schist Beds

Age of this tectonic folding is provided directly by the datations on biotites and muscovites as a witness of a low-grade metamorphism-In the basement. The Kibaran basement located on the eastern side of the Itombwe structure has been carefully studied in the Nya-Ngezie area located to the south of the Kivu Lake (Figure.8) by Villeneuve . In this area the Kibaran basement belongs to the cycle K5 of the Kibaran Orogen [6,2].

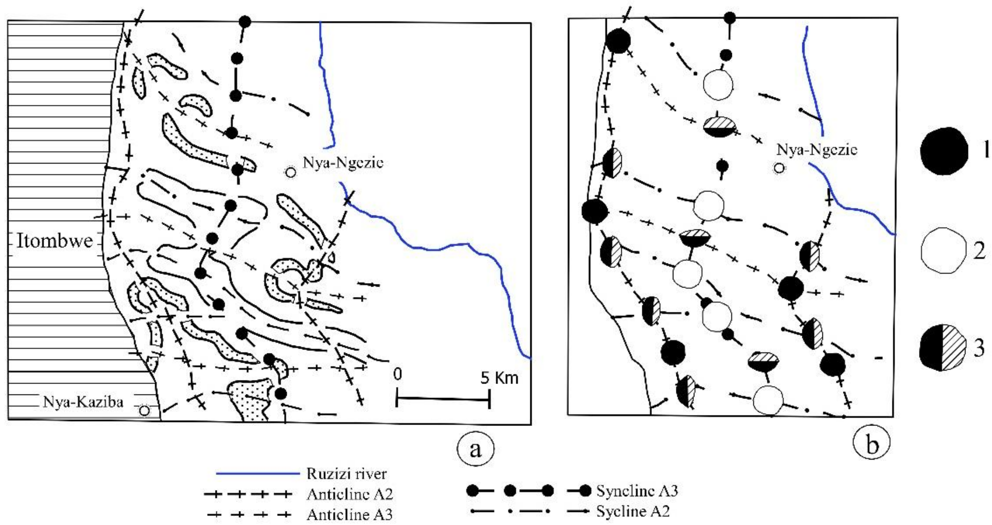

Figure 8: Interferences Between the NW-SE Kibaran Structures P2 and the N-S Post Kibaran P3 in the Nya-Ngezie area Located on the Eastern Flank of the Itombwe Syncline. The Reworking of the P2 Structures is Linked to the Itombwe Folding During the Pan-African Tectonic Event. Figure.8a: Kilometric Anticlines and Synclines in the Kibaran Basement. Fig.8b-Interpretation of the "egg box" Structures: 1- Domes by Interference of Two Anticlines, 2-Bowls by Interference of Two Synclines, 3- Interferences of Mixed Structures: Anticline/Syncline Versus Syncline/Anticline

The NW-SE regional structures (anticlines and synclines) are ascribed to the last Kibaran event (A2 = KV4) meanwhile the superimposed N-S (A3= Itombwe folding phase) structures are ascribed to the Itombwe tectonic event. The interpretation of this superimposition is shown in Figure 8b. But in this regional scale, the Kibaran structures A2 (KV4) are little deformed by the Itombwe structures A3 as it is shown in Figure. 9 which is a 3D interpretation of the Kibaran structures presented in Figure. 8a.

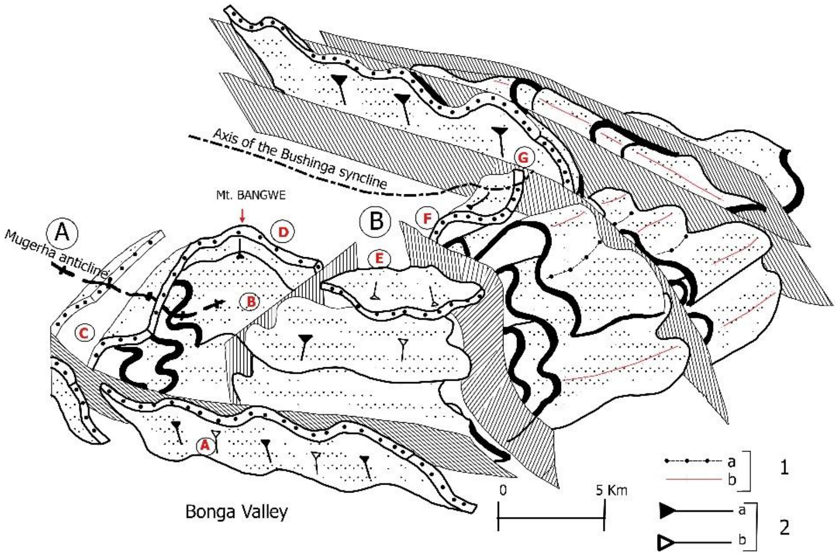

Figure 9: 3D diagram. Illustration of Reworking of the P2 (Kibarian Folding) by the P3 (Pan-African folding), in the Nya-Ngezie Area

This reworking is dated by Ar/Ar method on biotites from the rocks (C166 and 766) belonging to the cycle 4 (KV4) of the Kibaran orogeny. These datations on micashists and quartz–micaschists provides 2 plateau-ages respectively 573.2+/-1.6 Ma and 546.3 +/-1.7 Ma [3]. Indicating a Pan-African reworking. Similar Pan-African ages have been recorded in granitic intrusions within the Kibaran basement. Table III shown some examples of this Pan-African reworking.

Location	Method	Age	Samples	References
Kasika	Rb/Sr (microcline)	ca.520+/-9 Ma	G2/G4 granits	Monteyne et al. [30]
Kirumba	Rb/Sr (whole rock)	ca.578+/-9 Ma	G4 granit	Cahen et al. [31]
Numbi	Rb/Sr (whole rock)	ca.648 Ma	G4 granit	Cahen et al. [31]
Kadubu Riv.	Ar/Ar (muscovite)	ca.575+/-83Ma	Phyllite Itombwe	Walemba & Master [13]
Kahuzi	K/Ar (whole rock)	452+/-11 Ma	Neoprot. com	Vellutini et al. [21]
Biega	K/Ar (whole rock)	442+/-11 Ma	Neoprot. com	Vellutini et al. [21]

Table 3: G4: Kibaran Granites, Neoprot. Com: Neoproterozoic Complex

The best example of this Pan-African reworking is the Kasika granite to the west of the Itombwe trough and which is linked to the post Kibaran intrusion dated at 986+/- 10 Ma by Tack et al. with U-Pb on zircons and yielded an age between 549+/- 7 Ma and Rb/Sr age of 520+/- 9 Ma on microcline by Monteyne-Poulaert [32,30]. Another example is given by the Kahuzi and Biega massifs considered as a part of the tertiary volcanic outpouring linked to the East African rift and which yield ages between 440 and 505 Ma for the Kahuzi by Ar/K on whole rocks and 825.2 +/-5 Ma, 808+/-6 Ma with U-Pb on zircons from the same massifs. Such reworking is common in this area as well as in Rwanda as in Burundi. For example, Van Deale and Sherer found ages of 602.3 Ma+/-1.1 Ma and 618.9+/-1.6 Ma with Lu-Hf on grenats –micaschists close to Kibuye, in Rwanda. Taking into account the discrepancies induced by the different radiometric methods, we are considering two stages of deformations: first in Rwanda (618-602 Ma) and the second one related to the Itombwe folding (546-513 Ma) [21,34,35].

Post Rifting

There is no direct evidence of post rifting data on the Itombwe belt. But considering reworking of the Kahuzi and Biega, located in the western side of the Itombwe by the late Ediacarian-Early Cambrian (452- 442+/-11 Ma,) we are considering this extensional event as the post-rift stage of this Neoproterozoic rifting. The previous Tertiary- Quaternary ages given by Boutakoff, are not confirmed by the radiometric ages [21].

Origin of Orogenic Driving Force and Tectonic Transfer

Considering that there is no driving force in the studied area, we should have a look to the neighbouring belts in order to locate this active tectonic zone and also understand how these local tectonic activities have been transmitted from these active zones located at least 500km far away from our studied zone. These active tectonic zones were obviously located in the surrounding Pan-African belts. The central African belts concerned here are located between the Congo Craton (CC) including the Tanzanian Shield (TS), the Dharwar Craton (DC), the Rhodesian Shield (RS) and the northern part of the Kalahari Craton (Figure. 10).

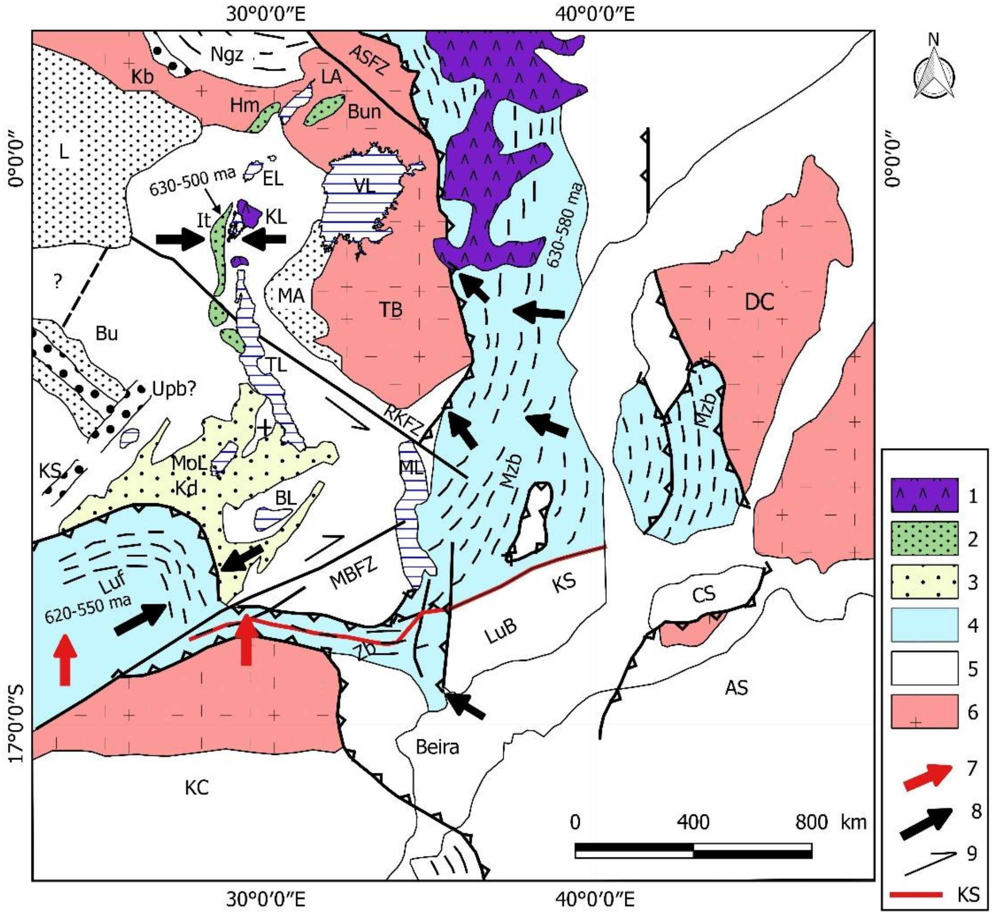

Figure 10: Pan-African and Cenozoic Lavas in East Africa

Legend: 1- Cenozoic and Quaternary lavas linked to the East African Rift. 2- Neoproterozoic rift, 3-Kundelungu aulacogen (Molassic formations), 4-Panafrican belts, 5-Basement (mainly kibarian), 6- ante Kibarian basements, 7- Displacement direction by the early Neoproterozoic, 8-Displacements of blocks during the Pan-African tectonic event, 9- Strike-slips along the transverse faults. KS-Kuunga suture, TB- Tanzanian Block, KC, Kalahari Craton, DC- Dharwar block, Kb-Kibalian, KS-Kasai Shield, AS-Antarctic Shield, CS- Shri-Lanka block, Kd- Kundelungu aulacogen, Luf- Lufilian belt (or Katangan belt), Zb-Zambezi belt, Lub-Luiro belt, (or Nampula block), Mzb- Mozambique Belt, L-Lindian, MA-Malagarasian, Ngz-Nyangara-Zemio belt, Hm-Mount Homa belt, Bun-Bunyoro belt, Upb-Upemba belt, Bu- Bushimay belt, ASFZ- Aswa Fault Zone, RKFZ- Rukwe Fault Zone, MBFZ-Mwenbezi Fault Zone, ML-Malagarasi Lake, TL-Tanganyika Lake, KL-Kivu Lake, EL-Edouard Lake, LA-Lake Albert, VL-Victoria Lake, BL-Bangwelo Lake, MoL-Moero Lake.

These belts are: the East African belt (EAB) to the East and the Katangan belts (Luf) and Zambezi-Kuungan belt to the South. The tectonic activities were likely transmitted either by superimposition of new deformations onto the old basement either by tectonic transfers along the strike-slip zones or by a combination of both processes.

The Pan-African structures in Eastern Africa

Pan-African belts

East African belt

The East African belt which runs from the Arabia to the Mozambique includes several segments: Egypt-Arabia, Ethiopian-Tanzanian and Madagascar-Mozambique only the last one could interest the Kivu Area.

The Madagascar-Mozambique Segment

The Mozambique belt is made with Kibaran basement terranes reworked during the Pan-African orogeny. Shackleton takes into account an internal anomaly in the Mozambique belt as the suture between the western and eastern Gondwana [36-39]. According to Fitzsimons and Hulscher the main steps of the geodynamical evolution are:

- 850 Ma two different oceans separated the Great Congo Craton (Tanzanian block and Irumide belt), the Itremo block and the Darwar craton
- 750 Ma. Both oceans subducted to the West give rise to two volcanic arcs.
- 650 Ma the Itremo and Darwar blocks collided while the subduction between the Itremo Block and the Congo Craton was still active. However, the corresponding slab had a vergence to the west according to Fitzsimons and Hulscher [39] while Cutten et al [40] support a vergence to the east with Granulitic massifs obducted to the Congo craton (Tanzanian Block). The thrusting of "nappes" is clearly to the west.

• 550 Ma the three blocks (Dharwar, Itremo and Congo) are grouped by collision of the two last blocks.
• 530 to 480 Ma. This last stage considered as a post tectonic extensible event could be linked to the E-W Kuunga collision [41]. But Goscombe et al. consider only one block facing the Congo Craton: the Azania Block (AZ) which collided with the Congo craton during the Adamastor/Mozambique phase (660-640 Ma). Taking into account the radiometric ages of the thermo-tectonic events delivered by twelve different authors (Figure.11), three mains different tectonothermal events are considered: 1-(580 -630 Ma), 2- (560-520 Ma), 3-(500 Ma). However, four radiometric datations between 700 and 850 Ma have also been recorded. Despite large discrepancies owing to the different radiometric methods, these ages seem to be coherent with the events in adjacent belts [41].

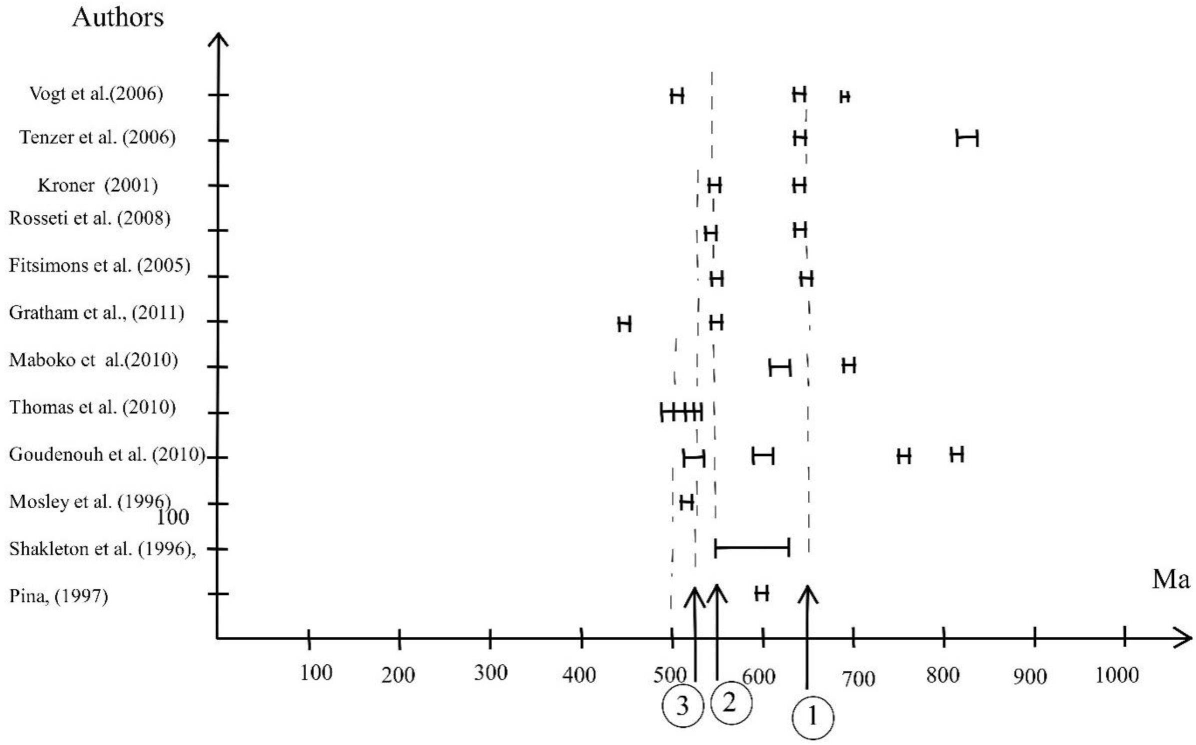

Figure 11: The Main Panafrican Thermo-Tectonic Events According to the Radiometric Data Delivered by Twelve Authors

Legend : Pinna Shakleton et al. [36,38], Mosley, Thomas et al. [42,43], Maboko et al. [44]. Grantham et al. [37]. Fitzsimons et al. [39]. Rosseti et al. Kroner, Tenzer et al. Vogt et al. Circled number: the main Panafrican events in Eastern Africa [45-48].

The Katangan Belt (or Lufilian Belt)

This belt is the most studied in central Africa owing to its copper mineralization. This belt consists in a very complex Lufilian arc thrusted over the Kundelungu aulacogen (or rift) considered as a molassic stage. At first this belt includes two main stratigraphic sections: at the base the Roan super-group (870-880 Ma to 735Ma) studied by Unrug and on top the Kundelungu super-group (735-575 Ma) divided into Lower and Upper Kundelungu groups. The Lower beginning by the "Grand conglomerat" linked to the Sturtian glacial event (717-660 Ma) and the Upper beginning by the "Petit conglomerat" linked to the Marinhoan Glacial event (650 -635 Ma). This stratigraphic subdivision was modified in 2003 by Wendorff who differenciated three stratigraphic groups: the Roan group (880 to 760 Ma), the Mwashya and Guba group (760-620 Ma) and the Fungurume group (620-500 Ma). The middle part (Mwashya and Guba groups) includes three main conglomerates: Nzilo conglomerate linked to the Kaigas glacial event (770-735) by Cailteux and de Putter , the "Grand conglomerat" linked to the Sturtian glacial event and the "Petit conglomerate" linked to the Marinhoan glacial event (630-650 Ma). But according to the very complex tectonic evolution of this belt evidenced by François , two main folding, D1 and D2 have been evidenced [49-52]. More recently (2019) Cailteux and de Putter [51]. Propose an age of 595 Ma for D1 and 550 to 530 Ma for D2.

Zambezi-Kuungan Belt

According to Hanson et al. the Zambezi belt located between the Bangweulu Block and the Zimbabwe craton is cut by the WSW-ENE Mwenbeshi Fault [53]. The basement is intruded by Kibaran granites (1100 to 1106 Ma) and granitic complexes at ca. 880 and 820 Ma. The last tectonic 820 Ma. The last tectonic events occurred between 590 to 530 Ma together with the Mwenbeshi Fault activity [53]. However, according to Goscombe et al. the geological evolution of this Zambezi-Kuunga block is more complex. They consider an oceanic plate separating the Kalahari and Congo cratons until the collision of both cratons. This collisional process could be divided in two phases: the Kaokoan/Zambezi Phase (590-570 Ma) which involves the eastern Luiro, Zambezi and Lufilian belts and the Damaran/Kuunga Phase (555-515 Ma) which involves the western Damara and Gariep belts. Thus, the limit between the northern Katangan, Muva and West

Zambia belts and the southern Nampula and West Zambezi blocks, is the E-W "Kuunga suture"[41].

Pan-African Transcurrent Shears Zones

Several fault zones perpendicular or with an "oblique angle" with respect to the belts have been evidenced but the main ones are (Figure. 10): The Aswa FZ (ASFZ) to the north, The Rukwa FZ (RKFZ) in the middle and the Mwembezi FZ (MBFZ) to the South. Obviously, they are operating at many times depending of the surrounding tectonic events which are poorly dated.

Aswa FZ (ASFZ)

The ASWA fault zone which separate the Mozambique belt from the Northern Pan-African belts (From Sudan to Arabia) has been well studied at many times: Chorowicz et al. and Chorowicz , Fernandez-Alonso et al. Saalman et, al. [54-57]. According to Saalman et, al. [57]. The main events recorded by U-Pb on zircons yielded two main ages for sinistral strike-slip: 686 and 640 Ma. Chorowicz et al. [54]. Recorded 2 ages: 660 Ma and 685-655 Ma

Rukwa FZ (RKFZ)

The NW-SE Rukwa Fault Zone located between the Tanzanian craton and the Bangweulu block is setting within the Ubendian (Paleoproterozoic) basement. It was active at many times: during the Kibaran orogen (Wakole terrane), the Neoproterozoic at ca. 724+/-6 Ma (58) and at 601+/-7 Ma and 596+/-41 Ma and [58-60]. The strike-slip motion along this fault zone could change in time. More recents activities are registered but not radiometric dated

Mwenbeshi FZ

The Mwenbeshi Fault zone located between the Bangweulu block and the Kalahari Craton. Well studied by Daly the last tectonic events occurred between 590 to 530 Ma [61,53]. The strike slips motions have been changed with time. Daly and Unrug favoured a sinistral strike-slip and Durr and Dingeldey and Jackson et al. a dextral strike-slip at 650 Ma [61-64].

Other FZ

Obviously, similar faults with strike-slip motions have been evidenced like the Chongwa Fault Zone which I associated to the Mwenbeshi FZ.

Radiometric Data

The main radiometric data ascribed to the tectonic events linked to these shear zone, are shown in Figure.12.

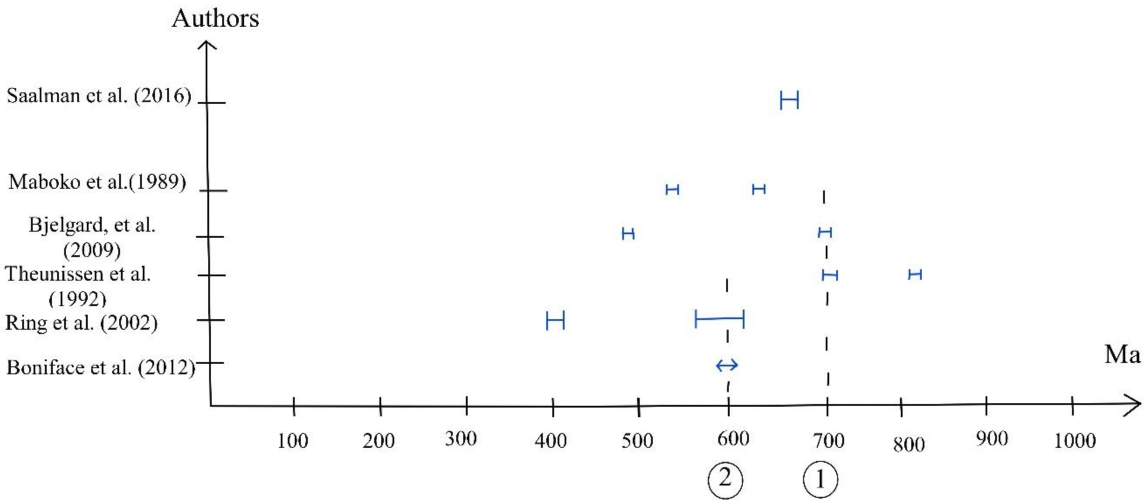

Figure 12: The Main Thermo-Tectonic Events Recorded on the Transcurrent Faults, According to the Radiometric Data Delivered by Six Authors

Legend : Boniface et al. [59]. Ring et al. [65]. Theunissen et al. [58]. Bjelgard et al. [66]. Maboko et al. [67]. Saalman et al. [57].

The Figure above shows that the main tectonic events recorded by radiometric methods are comprised between 800 and 400 Ma with two concentrations at 700Ma and 600 Ma. The tectonic events linked to the Cainozoic to Quaternary East African Rift have not been recorded in radiometric data

Geodynamic interpretations of the Itombwe and related structures.

Obviously, several models have been proposed to explain this Itombwe trough. Chorowicz et al. [68]. Proposed to link the structures of the Neoproterozoic rift to a large SW-NE sinistral fault running from Katanga to Uganda. This strike-slip system which was associated to a parallel dextral strike-slip system in the western side of the Congo basin was used to explain the structure of this basin (Figure 13).

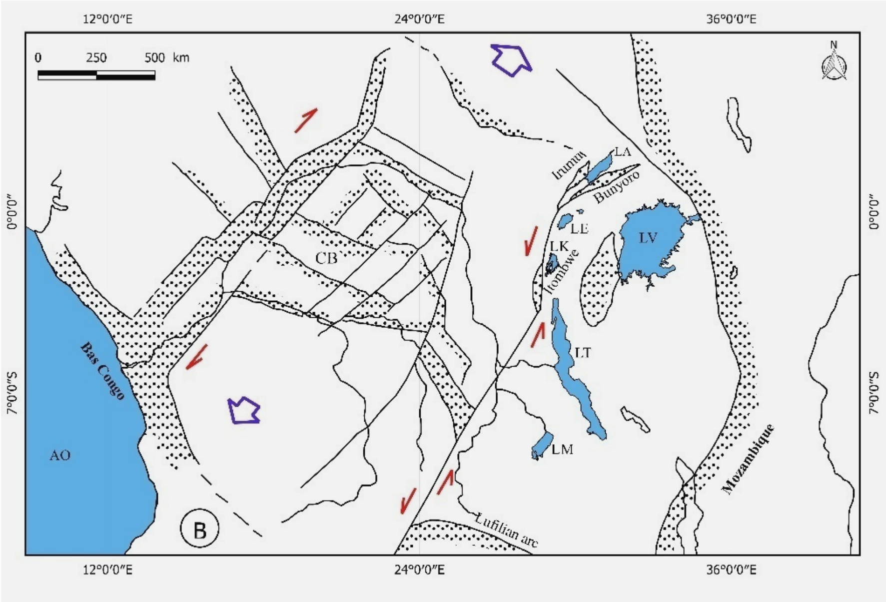

Figure 13: Neoproterozoic Structuration of the Congo Basin (Chorowicz et al. [68] Modified)

Legend: CB-Congo basin, LM- Lake Moero, LT- Lake Tanganyika, LK-Lake Kivu, LE-Lake Edouard, LA-Lake Albert. LV- Lake Victoria. Red arrow- Strike-slips, violet arrows- tectonic stress.

On the other hand, Kampunzu et al [29]. Have proposed an opening of the N-S Itombwe through in relation with the E-W Lufilian belt similarly to the Cainozoic N-S Baikal rift which is associated to the E-W Himalaya belt. However, if the age of the opening (662 Ma) and folding of the Itombwe trough (562 Ma) are not totally consistent with the Lufilian arc evolution. The D1 (595 Ma) tectonic events recorded in the Lufilian arc is not consistent with the folding of the Itombwe syncline. On the contrary, the D2 tectonic event (550-530 Ma) is consistent with the post tectonic evolution of the Itombwe belt. Although the lack of a Sturtian glacial event in the Itombwe is consistent with an opening later than 660 Ma, the occurrence of Marinoan deposits (650-635 Ma) are older than the main tectonic event in the Lufilian arc (602 Ma). So, the Lufilian belt could not be directly linked to the Itombwe opening. In the present status of knowledge, we ascribe the Itombwe through opening to a dextral strike-slip displacement along the Rukwa-Fault Zone which is located in the southern part of the Itombwe. In taking in consideration that the fold axis in the Itombwe are N-S similarly to those of the East African belts we are ascribing the closure of this Itombwe trough to the East Pan-African belts. In our hypothesis, the tectonic folding in the Itombwe trough has been transmitted by the East African belt, partly by tectonic transfer along this Rukwa-Fault zone and partly by deformation of the basement. But, the D2 tectonic event evidenced the Lufilian arc and associated to the Kuunga event could be linked to the post Itombwe folding.

Discussion

This discussion intends to understand the evolution of this part of Africa during the Panafrican orogeny mainly in the Neoproterozoic. We also have in purpose to point out the not yet understandable part of this rift process and to provide some paths for next researches.

Geodynamic Evolution the Neoproterozoic in Central and Eastern Africa

In paragraph 3, five stages of evolution have been distinguished: P1 (950-850 Ma), P2- (850-700 Ma), P3- (650- 620 Ma), P4 (620-550 Ma) and P5 (550-500Ma). But only three main stages are illustrated in Figure. 14: the pre-collisional stage P2 (Figure 14a), the collisional stage P4 (Figure 14b) and the post collisional stage (stage P5) in the Mozambique belt, (Figure 14c) which also correspond to the collision with the southern blocks at the end of the Kuunga orogeny. However, there are some Kibarian inherited structures related to this Neoproterozoic rift. For example, the K4 Kibaran stage (1120-1020 Ma) which consists of a narrow N-S trough parallel to the Itombwe and recorded between the Kivu Lake and the Itombwe trough, could be an ancestor of the Itombwe trough. These N-S Kibarian structures may have guided the Pan-African troughs.

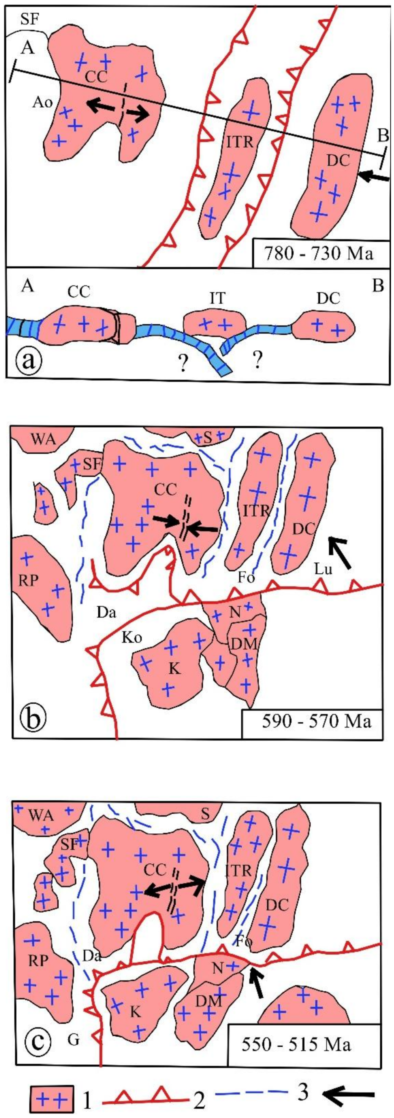

Figure 14: Illustration of Three Main Stages in the Geodynamic Evolution of the Panafrican Belts in Central and Eastern Africa

Legend: 1- Cratons, 2- Subduction zones and sutures, 3-Belts, 4- Moving direction of blocks, CC-Congo Craton, DC-Dharwar Craton, K-Kalahari craton, ITR-Itremo Block, DM-Droning-Maud Block, M-Mawson block, Ao-Adamastor Ocean, SF- Sao-Francisco block, WA-West African craton, S-Saharan Craton, RP- Rio de la Plata Block , Da-Damara ocean, DM-Damara Belt, G- Gariep Belt, Ko-Khomas Ocean

These Main Stages are:

- **Stage P1-** (950-850 Ma) this is a quiet period in the Kivu area (lack of zircons between 900 to 800 Ma) which corresponds with an extensive period with Oceans between the main future Panafrican blocks, the deposition of the Roan group in Katanga supergroup and likely to the doming of the Kivu Lake area (Figure. 3b)

- **Stage P2-** (850-700 Ma) Intrusions of anorogenic magmatic rocks by extensive relaxation in the doming area and deposition of parts of the Lindian and Malagarasian covers in both sides of the Kivu Lake area.

- **Stage P3-** (650- 620 Ma): a stage giving rise to the main collisional events in the Eastern Panafrican belts which could have reactivated the transcurrent fault zones

- **Stage P4-** (620-550 Ma). Last tectonic events in the Mozambique belts with the collision between the Itremo block and Congo craton. This tectonic event provides the folding of the Itombwe trough and other associate rifting troughs. We are also supposing that this tectonic event could have again deformed the Lufilian belt.

- **Stage P5-** (550- 500Ma). Corresponds to the N-S collision between the Congo craton and the newly accreted terranes with the Kalahari craton and Nampula block (Figure.10 and 14c). This collision which followed the subduction of the Khomas Ocean below the Congo Craton provides an E-W relaxation with extensive deformations in the studied area including the reworking of the Kahuzi and Biega massifs by the early Cambrian (456 and .446 Ma). The D2 event (550-530 Ma) in the Lufilian arc could be linked to this southern envent.

Questions Marks

Despite these news data on the Neoproterozoic rifting some questions are still unsolved:
• The ratios in the shortening by folding and by strike-slip motions.
• The inheritance of the Last Kibaran tectonic event on the Neoproterozoic rift.
• Although we are in a weak zone between two cratons, we don't know the origin of the doming and the extension in the early stage of the Neoproterozoic rift.
• The relationships between the coeval sediments in the Neoproterozoic rift and in the Lindien and Malagarasien flat covers.
• The impact of the Lufilian belt on the Neoproterozoic rift.
• The local extension or shortening of segments limited by fault zones with respect to the stability of adjacent segments. Why the southern segment of the Neoproterozoic Rift between the Itombwe belt and the Lufilian arc do not present any similar troughs?
• The relationships with more recent rifts like the Karoo rift or the East African rift

Conclusions

There is a big challenge to understand how the Pan-African belts in central and east Africa are acting through times from the Neoproterozoic to the Cambrian. But the second challenge was to connect the non-active coeval structures from the Neoproterozoic rift with the active Pan-African belts. The aim of our study is to understand the process of the tectonic transfer of active deformations from the belts resulting from a Wilson cycle, to the far away coeval passive structures. Our study implying microscopic thin sections, regional field observations and local plate tectonic knowledge answer to the demand of this special issue. Despite a lack of extensive observations between the Central African Neoproterozoic rift and the surrounding Pan-African belts, we are proposing a process of tectonic transfer involving the oblique transcurrent faults together with an history of the evolution of the central and east Africa since the end of the Mesoproterozoic Kibaran orogens (950 Ma) to the end of the Neoproterozoic to Cambrian Panafrican orogen (510 Ma). The location of the Neoproterozoic rift between the ASWA and Rukwa fault zones favor the relationships between Neoproterozoic rift and the transcurrent faults. Anyway, this Neoproterozoic rift deserves to be compared with modern analogs.

Data Availability Statement: The original contributions presented in this study are included in the article/ supplementary material. Further inquiries can be directed to the corresponding author(s).

Conflicts of Interest: The authors declare no conflict of interest.

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