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Persistent fault controlled basin formation since the Proterozoic along the Western Branch of the East African Rift

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Abstract—The Western Branch of the East African Rift System is outlined by elongate sedimentary basins, frequently occupied by Cenozoic rift lakes. The role of the inheritance of the leading rift faults from pre-existing basement structures has often been invoked. Recent studies in western Tanzania confirm the extent of the northwest orientated Palaeoproterozoic Ubende Belt contribution to the Phanerozoic Rift. Attention is drawn here on the occurrence of different Meso- and Neoproterozoic sedimentary basins that developed along the ductile shear belt as a result of repeated sinistral wrench fault reactivation. These basins partly overlap each other and typically bear shallow and weakly evolved sediments. North of the Ubende Belt, the Mesoproterozoic Kibara Belt is inferred to have originated as a basin controlled by the complex termination of the Ubende wrench fault.

Phanerozoic rift basins also develop along the northwest orientated Ubende Belt structure. They display the same elongate shape as the Proterozoic basins. In Late Palaeozoic-Early Mesozoic the Karoo rift basins formed from a dextral lateral shear reactivation of the inherited Proterozoic shear faults. During the first phase of development the Lake Tanganyika Basin is believed to bear the same characteristics as all previous basins along the Ubende Shear Belt, mainly controlled by strike-slip movements along pre-existing shear faults. The present Lake Tanganyika Basin is subdivided in two sub-basins, separated by the transverse Mahali Shoal, which is an active structure located on the Ubende Shear. The deep lake basin mainly developed outside the Ubende Belt. The northern sub-basin appears to be structurally controlled by the reactivation of the Mesoproterozoic sinistral wrench fault termination of the Ubende shear faults. Structural control of the Palaeoproterozoic basement is however unclear for the southern sub-basin of Lake Tanganyika: this part of the rift segment is flanked by Palaeoproterozoic basement which has not been affected by the Ubende Shear. © *1998 Elsevier Science Limited.*

Résumé—La branche occidentale du rift est-africain est caractérisée par une série de bassins sédimentaires, souvent occupés par des lacs de rift. L'influence des structures pré-existantes du socle comme héritage des structures principales du rift a été souvent invoquée. Des études récentes en Tanzanie occidentale confirment l'importance de la contribution des structures paleoprotérozoïques orientées NW-SE de la chaîne ubendienne aux structures phanérozoïques du rift. L'attention est attirée ici sur la présence de bassins sédimentaires d'âge méso- à néoprotérozoïque, qui se sont développés le long de la zone de cisaillement ductile, suite à des réactivations décrochantes sénestres répétées. Ces bassins se superposent partiellement et contiennent typiquement des sédiments peu évolués, d'eau peu profonde. Au nord de la chaîne ubendienne, la chaîne mésoprotérozoïque Kibarienne est considérée comme issue d'un bassin contrôlé par la termination complexe du système décrochant ubendien.

Les bassins phanérozoïques se développent aussi le long de la structure NW-SE de la chaîne ubendienne. Ils ont la même forme allongée que les bassins protérozoïques.

Au cours du Paléozoïque tardif et du Mésozoïque précoce, les bassins de rift Karoo se sont formés par réactivation latérale dextre des failles ductiles héritées du Protérozoïque. Pendant sa première phase de développement, le bassin du Lac Tanganyika présente les mêmes charactéristiques que tous les bassins antérieurs situés le long de la chaîne cisaillante ubendienne et principalement contrôlés par des mouvements le long de failles pré-existantes. Le bassin actuel du Lac Tanganyika est subdivisé en deux sous-bassins, séparés par le seuil transverse des Mahali. Celui-ci est une structure active localisée sur un cisaillement ubendien. Le bassin lacustre profond s'est principalement développé en dehors de la chaîne ubendienne. Le sous-bassin nord apparaît comme controllé structuralement par la réactivation de la terminaison des cisaillements ubendiens mésoprotérozoïques. Le contrôle structural du socle paléoprotérozoïque est cependant peu clair pour le sous-bassin sud du Lac Tanganyika. Cette partie du rift est bordée de socle paléoprotérozoïque non affecté par le cisaillement ubendien.

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INTRODUCTION

Continental rifts avoid cratonic regions while preferentially following pre-existing basement weaknesses. In the East African continent they are generally associated with belts developing during the Neoproterozoic Pan-African evolution. Although this is the case for the Eastern Rift Branch (Mozambique Belt), it does not apply for the Western Branch of the East African Rift with a northwest trending southern segment and a more northeast trending northern segment (inset Fig. 1).

West of the Tanzanian Archean Craton the Western Branch of the East African Rift overlies the Palaeoproterozoic Ubende Belt (McConnell, 1972). The rift inherited a large part of its northwest trending fault pattern. The Western Branch switches to a north-south trend as soon as it enters the domain of the Mesoproterozoic Kibara Belt, immediately north of the Ubende Belt. In this domain the rift develops at an angle to the regional trend of the Kibara folding (Klerkx *et al.*, 1987) and the "leading basement weakness" followed by the rift in this region is less evident. More problematic is the basement structure that contributed to the formation of the southern and most recent sub-basin of the Lake Tanganyika Rift Zone.

The Western Branch characteristically bears elongate and narrow sedimentary basins, frequently occupied by deep rift lakes. Gravity survey and drilling were carried out only in the Rukwa Basin (Peirce and Lipkov, 1988; Wescott *et al.*, 1991), and seismic reflection surveys were performed in the Rukwa, Tanganyika and Malawi Basins (Sander and Rosendahl, 1989; Specht and Rosendahl, 1989; Morley *et al.*, 1992; Kilembe and Rosendahl, 1992). These geophysical studies provided a wealth of information on the present intracontinental rift evolution. In summary, Rosendahl (1987) introduced the "half-graben" concept in the East African Rift and Morley *et al.* (1990) emphasised on the high abundance of overlapping "transfer" zones, on the weak expression and the reduced occurrence of large scale cross faults and on the low extension of the upper crust. Various papers reported different extensional stress field conditions for the rifting (Kazmin, 1980; Chorowicz and Mukonki, 1980; Tiercelin *et al.*, 1988; Delvaux *et al.*, 1992; Ring *et al.*, 1992). In the widely applied half-graben hypothesis the authors do not consider the present rift geometry to be as strongly controlled by pre-rift basement structure as this paper proposes. On the other hand, the interpretation of Morley *et al.* (1990) strongly reflects similarities between the general Phanerozoic rifting and some evolutionary characteristics of the basement prior to the rifting.

Daly *et al.* (1989, 1991) suggested that in the Late Palaeozoic the sedimentation and tectonics of the Karoo basins along the southern segment of the Western Rift Branch, were controlled by dextral strike-slip reactivation of the Ubende structures. The deep Rukwa Rift Basin with its thick sedimentary infill, is believed to have been initiated in that early stage, as do the Kalemie and north Malawi Basins (Fig. 1), which all extend along a northwest trend, parallel to the Ubende Belt leading structure (Delvaux, 1991).

In this present paper attention is drawn to the occurrence in parts of the Phanerozoic rifted zone, of fault controlled and locally elongate Proterozoic sedimentary basins, which all display very shallow level evolution. The geometry of these basins is largely inherited from the northwest trending structures of the Proterozoic

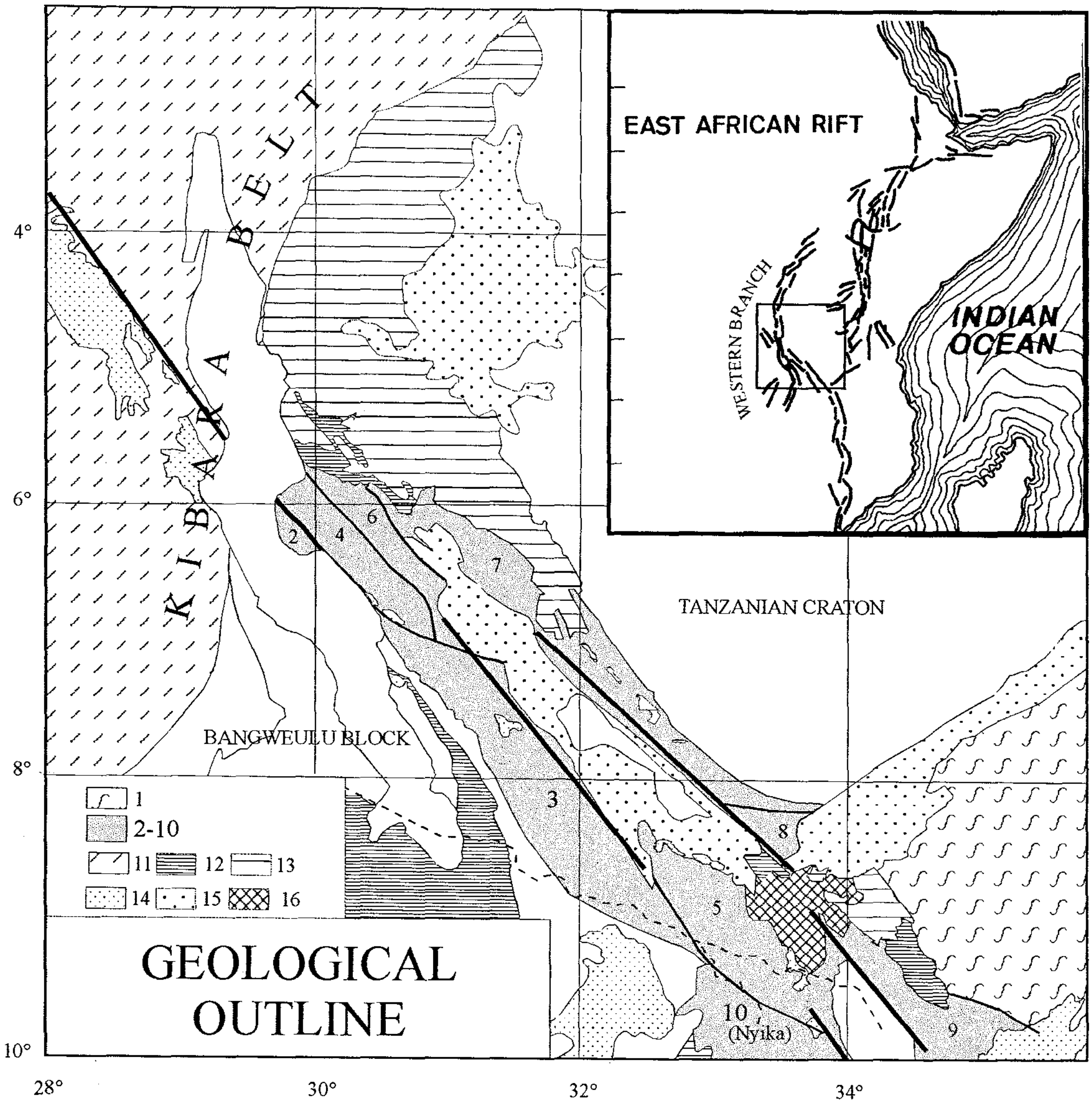


Figure 1. *Location and geological outline of the region. In between cratonic blocks (the Bangweulu Block in the west and the Tanzanian Archean craton in the east) the Phanerozoic rift follows the regional trend of the Ubende Shear Belt. Inset shows the location of the area in the Western Branch of the East African Rift. 1: Palaeoproterozoic east-northeast - west-southwest orientated Usagara Belt; 2-10: Palaeoproterozoic northwest-southeast orientated Ubende Shear Belt with indication of the different fault bounded terranes: 2: Mahali; 3: Ufipa; 4: Ubende; 5: Mbozi; 6: Wansisi; 7: Katuma; 8: Lupa; 9: Ukenju; 10: Nyika (in Malawi); 11: Mesoproterozoic northeast-southwest trending Kibara Fold Belt; 12: Mesoproterozoic sedimentary basins along the northwest orientated Ubende Belt; 13: Neoproterozoic sedimentary basins along the northwest orientated Ubende Belt; 14: Karoo outcropping area; 15: Cenozoic deposits; 16: Rungwe Quaternary volcanics.*

basement (Theunissen *et al.*, 1996). Even basins which are oblique to the general trend of the Ubende Belt are considered to be controlled by basement fault reactivation - the Kibara Basin at its northern end in particular is interpreted as a Mesoproterozoic sinistral wrench fault termination setting of the Ubende Shear Zone (Fernandez-Alonso and Theunissen, *in press*).

The tectonic control of the Lake Tanganyika Basin in its present stage of evolution is much less evident. In contrast with the pre-Cenozoic evolutionary stages, which are all characterised by shallow basins, the Cenozoic basins are deep water basins and developed mainly outside the Ubende Belt itself. The Lake Tanganyika Basin can be subdivided into a northern and southern sub-basin, separated by the Mahali Shoal and accommodation zone, which is an active transverse structure located upon the Ubende Shear Zone. The northern sub-basin appears to be controlled by a Mesoproterozoic sinistral wrench fault termination. The southern sub-basin is orientated at a minor angle to the Ubende trend. It is flanked on both sides by Palaeoproterozoic basement which is not affected by the Ubende Shear and which is overlain by weakly deformed, non-metamorphosed and shallow level Proterozoic sediments.

WRENCH FAULT REACTIVATIONS IN THE PALAEOPROTEROZOIC UBENDE SHEAR BELT

With a northwest structural trend, the Palaeoproterozoic Ubende Shear Belt of western Tanzania extends for more than 500 km with an average width of 50 km (Fig. 1). To the west the belt is bounded by the Palaeoproterozoic Bangweulu Block (overlain by the Mesoproterozoic Mporokoso Beds, Fig. 1), while to the east the belt is flanked by the Tanzanian Archean Craton in the northern part and by the Palaeoproterozoic Usagara Belt in the southern part (Fig. 1). The boundaries between both these Palaeoproterozoic fold belts and the Tanzanian Craton are frequently masked by the late Palaeoproterozoic granites (Lenoir *et al.*, 1994). In an elongate and block shaped shear pattern (McConnell, 1967) the pre-existing terranes (numbered 2-10 on Fig. 1) of the Ubende Belt have been set in the northwest trending shear zone, best outlined by the highly sheared terrane boundaries. In a general Palaeoproterozoic plate tectonic model (Daly *et al.*, 1985; Daly, 1986) the northwest trending Ubende Belt has been proposed as a lateral accretion zone, while the more west-east trending Usagara Belt evolved as a frontal accretion event on the Tanzanian Craton. Recent studies in the region proposed that an early Palaeoproterozoic oblique suture preceded the main lateral shear deformation of the Ubende Belt (Theunissen *et al.*, 1996). Although the northwest orientated block pattern, bounded by linear faults was present since the early stages, its present outline is a result of persistent boundary reactivations in the Proterozoic, as well as the Phanerozoic (Daly *et al.*, 1989; Theunissen *et al.*, 1996). This characteristic has been described as a "perennial taphrogenic structure" (McConnell, 1972) and as a "long-lived fundamental structural weakness" (Sutton and Watson, 1986). It is also often cited as a typical example of repeated reactivation of steeply inclined shear fault zones.

The Palaeoproterozoic ductile shear belt

The Ubende Belt is composed of high-grade metamorphic sequences. They comprize mafic and ultramafic granulite facies and rare eclogite rocks (Sklyarov *et al.*, *in press*), which are preserved in the Mbozi and Ubende terranes (4 and 5 on Fig. 1). These terranes represent deeply subducted ophiolites, exhumed to the subsurface during the later Palaeoproterozoic and right lateral shear deformation (Boven *et al.*, *in prep.*). This phase of pronounced lateral shear has imposed to the entire Ubende Belt its characteristic northwest orientated fabric. Ductile shearing is variably distributed over the terranes. It is most intensely expressed along and associated with steeply dipping fold limbs along northwest trending corridors. The latter constitute the boundaries of the distinct terranes of the Ubende Belt (Fig. 1) (Theunissen *et al.*, 1996).

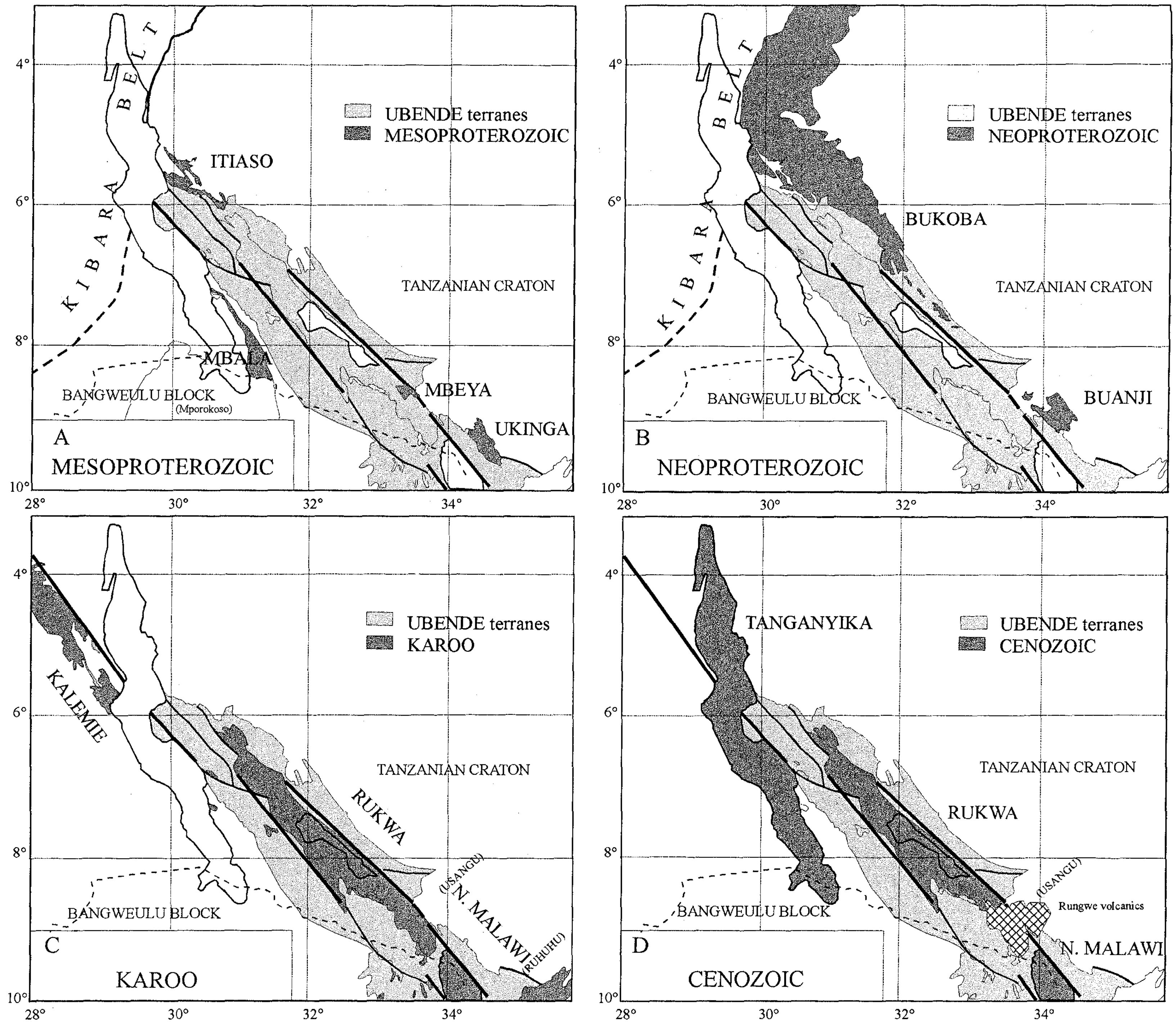
Proterozoic reactivations

Along the northwest trending and steeply inclined fold limbs and more particularly where these limbs coincide with terrane boundaries, the ductile dextral shear zones are frequently overprinted by mylonite sequences, which are concordantly interleaved in the ductile fabric. In sharp contrast with the ductile fabric, these mylonites display consistent sinistral strike-slip deformational characteristics in amphibolite-to greenschist-facies conditions (Theunissen *et al.*, 1996). These mylonites reflect a pluriphase reactivation of the ductile shear zones. Only in the southernmost part of the Ubende Belt has a Neoproterozoic age been obtained for the mylonites (Theunissen *et al.*, 1992). Geochronological evidence for such Neoproterozoic reactivation is lacking for the northern part. However, relative ages for the repeated sinistral strike-slip deformational regimes can be deduced from structural styles and setting shown by the nearby Meso- and Neoproterozoic sediments (Theunissen *et al.*, 1992, 1996).

Phanerozoic rift faulting

In the high-grade metamorphic Ubende Belt, northwest orientated ductile shear zones with interleaved ductile-brittle mylonites are well developed in between different terranes and constitute prominent mechanical anisotropies. These structures have been repeatedly reactivated during the Phanerozoic and have

Figure 2. *Consistent sedimentary basin formation along the northwest Ubende Shear Belt. (A) During the Mesoproterozoic: Itiaso, Mbala, Ukinga and Mbeya sedimentary basins. (B) Neoproterozoic sedimentary basins: Bukoba and Buanji. (C) Karoo (Permo-Triassic) basins: Kalemie, Rukwa and north Malawi. (D) Cenozoic basins covering Rukwa and part of Kalemie with the formation of deep lakes Tanganyika and north Malawi.*


UBENDE terranes
MESOPROTEROZOIC
ITIASO
KIBARA BELT
TANZANIAN CRATON
MBALA
MBEYA
UKINGA
BANGWEULU BLOCK
(Mporokoso)
A
MESOPROTEROZOIC
UBENDE terranes
NEOPROTEROZOIC
BUKOBA
KIBARA BELT
TANZANIAN CRATON
BUANJI
BANGWEULU BLOCK
B
NEOPROTEROZOIC
UBENDE terranes
KAROO
KALEMIE
TANZANIAN CRATON
RUKWA
(USANGU)
N. MALAWI
(RUHUHU)
BANGWEULU BLOCK
C
KAROO
TANGANYIKA
UBENDE terranes
CENOZOIC
TANZANIAN CRATON
RUKWA
(USANGU)
Rungwe volcanics
N. MALAWI
BANGWEULU BLOCK
D
CENOZOIC
4°
6°
8°
10°
28°
30°
32°
34°

largely contributed to the rift fault geometry. Some major northwest trending and brittle rift faults are associated with dextral strike-slip reactivation: the Ufipa Fault in the north (Chorowicz *et al.*, 1988) and the Livingstone Fault in the south (Wheeler and Karson, 1989; Wheeler and Rosendahl, 1994). However, these authors did not mention precise age constraints for the strike-slip movements. Delvaux *et al.* (1992) and Ring *et al.* (1992) have shown a complex succession of dextral strike-slip and normal fault movements along these northwest trending faults, concluding that the stress field was not stable and that the fault kinematics changed several times from the Late Palaeozoic to the present times.

More characteristic are the very deep rift basins, flanked by the superimposed, pluriphase Proterozoic and Phanerozoic faults, often representing master faults of these basins (Figs 1 and 2). The lack of stratigraphical time markers remains a major handicap in unravelling the complexity of rift faulting and its role in the formation of the succeeding basins.

Rifting also developed outside the Ubende Belt, as evidenced by the Lake Tanganyika Basin. In the south Lake Tanganyika sub-basin only sinistral wrench fault reactivation in the nearby Ubende Belt is assumed to control the rift faults. In the northern sub-basin the weakest structures are inferred to belong to the wrench fault termination of the Ubende Belt (Fernandez-Alonso and Theunissen, *in press*).

PROTEROZOIC SEDIMENTARY BASINS ALONG THE UBENDE BELT

Very low-grade metamorphic and shallow level sedimentary sequences, assigned to different Proterozoic units, are variably distributed upon and along the high-grade metamorphic Ubende Belt (Fig. 1). Inside the belt these sediments occur as narrow and elongate strips or patches, flanked by sheared basement. The sediments are more extended along the eastern and western boundaries of the belt, where they appear in Meso- and Neoproterozoic settings. It is however in the northern part of the Ubende Belt that the sedimentary sequences are most developed, particularly within the Mesoproterozoic Kibara Belt (Figs 1 and 2A). Along the contact between the Kibara Belt and the Tanzanian Craton, the Mesoproterozoic sediments are partly overlain by Neoproterozoic shallow level sedimentary and volcanic sequences (Tack, 1995).

As a rule, Neoproterozoic sediments overlap Mesoproterozoic deposits in many places. This is the case along the northwest trending wrench fault zone itself and its northwestern termination. It is assumed that basin forming processes in the Proterozoic concentrated in the same area by repeated reactivation of the same basement structures.

Basins inside the Ubende Belt

Patches (not outlined on the figures) of non-metamorphosed and weakly consolidated Proterozoic sediments locally overly the high-grade Ubende sequences. They have been described and mapped as the Ifume and Sanyika Formations along the Ufipa Shear Zone (Halligan, 1962; Smirnov *et al.,* 1973). They consist of polymictic conglomerates, sandstones and siltstones with thicknesses generally not exceeding a few hundreds of metres, except for the Mongwe conglomerate (400 m). The sequences are gently folded or tilted and contain numerous northwest striking faults and fractures. These Proterozoic, very shallow, arenaceous sediments testify for a tectonic activity along the inter-terrane boundary faults (Ufipa and Rukwa) of the Ubende Belt.

In the southern part of the belt, the Ukwama cataclasites are attributed to the Mesoproterozoic (Harpum and Harris, 1958). These rocks occur in narrow, elongate and northwest trending troughs of sheared greenschist-facies metasediments and volcanics. They sharply contrast with the surrounding Ubendian Belt meta-anorthosites (Theunissen *et al.,* 1996). The Ukwama sequences may be considered as equivalent to the badly outcropping Mbeya Range unit (Fig. 2A), which is correlated to the Mesoproterozoic Ukinga sediments (Klerkx and Nanyaro, 1988; Marobhe, 1989).

The Proterozoic sediments within the northern part of the Ubende Belt are weakly deformed and have less well outlined depocentres (Ifume, Sanyika and Mongwe). In the south they are sheared and confined to narrow and northwest trending elongate troughs (Ukwama and Mbeya).

Basins along the margins of the Ubende Belt

Shallow arenitic and arenopelitic sediments occur over an extended area along the eastern (Ukinga, Buanji) and the western (Mbala) boundaries of the Ubende Belt (Fig. 2A, B).

The Ukinga-Buanji Basin

In the southeast the Kipengere Mountain Range (Fig. 2) is composed of low-grade metamorphic and predominant pelitic sediments with subordinate arenaceous horizons. The sediments unconformably overly the Ubendian crystalline basement rocks and have been identified as the Mesoproterozoic Ukinga Group (Harpum and Harris, 1958). Highly sheared along their western boundary with the meta-anorthositic Ubendian Belt, these sediments are almost undeformed in their eastern part (Klerkx and Nanyaro, 1988; Theunissen *et al.*, 1996). These Ukinga Beds have been associated with the areno-pelitic schistose rocks outcropping in the Mbeya Range (Marobhe, 1989). The northern part of the Ukinga Basin is unconformably overlain by the Neoproterozoic Buanji Group, consisting of shales with interbedded quartzites, succeeded by limestones and topped by andesitic lavas (Harpum and Harris, 1958; Maloney and Downie, 1972; Piper, 1975). Geophysical studies (Marobhe, 1989) estimated a 4.7 km sedimentary thickness for the Ukinga-Buanji Basin.

The Mbala Basin

West of the Ubende Belt (Fig. 2A) shallow and almost undeformed sandy and pelitic Mbala sediments outcrop along the southern flanks of Lake Tanganyika. Page (1960) considered these sequences as equivalent to the Neoproterozoic Bukoba Beds. Unrug (1984) proposed a Mesoproterozoic age and correlated them to the Mporokoso Beds along the Bangweulu Plateau in adjacent Zambia (Figs 1 and 2A). The Mbala Beds unconformably overly the weakly deformed and almost unmetamorphosed volcano-plutonic complex of Kate-Kipili of late Palaeoproterozoic age (Lenoir *et al.*, 1994). The Mbala Beds along the eastern boundary display local shearing associated with sinistral strike-slip deformation, which is best evidenced in the shallow level Kate-Kipili Palaeoproterozoic basement rocks (Theunissen *et al.*, 1996). The Mbala sequences lithologically resemble the Bukoba sandstone unit, which extends southeast of the Kibara Belt (Fig. 1). Commonly attributed to the Neoproterozoic, the Bukoban sandstones have been recently interpreted as being Mesoproterozoic (Tack *et al.*, 1992; Tack, 1995).

The Itiaso-Bukoba Basin

North of the Ubende Shear Belt (Figs 1 and 2A, B) lies a vast region of weakly deformed sedimentary sequences, known as the Mesoproterozoic Itiaso Group and the Neoproterozoic Bukoba Group (Halligan, 1962). The Itiaso sediments are predominantly composed of dark gray shales with subordinate quartzites, while the Bukoba units are composed of a thick succession of sandstones and shales, succeeded by limestones and basalts. Halligan (1962) reported that the Itiaso Beds are several thousand meters thick and were deposited in a narrow tectonic trough, confined to the westernmost part of the region, near the Lake Tanganyika border. The Itiaso Beds are aligned along northwest-southeast trending upright folds and folding is increasingly complex towards the west while dying out to the east. The Neoproterozoic Bukoba sediments unconformably overly the Itiaso Beds. They are very weakly folded and again show more deformation to the west.

TECTONIC CONTROL OF PROTEROZOIC BASINS

Proterozoic sediments are preferentially deposited along the borders of the Ubende Belt are less developed within the belt. The Mesoproterozoic sediments are more deformed than the Neoproterozoic ones. Mesoproterozoic basins seem to have nucleated along reactivated Ubende shear faults. The same mechanism of basin formation prevails during the Neoproterozoic.

Mesoproterozoic basins along the Ubende Belt

While the age of the Mbala Beds is questionable, the Itiaso and Ukinga sediments occurring along the eastern boundary of the Ubende Belt are definitively of Mesoproterozoic age (Fig. 2A).

The Ukinga and Mbeya Groups

The Ukinga and Mbeya Groups have been related to strike-slip reactivation along the northwest orientated Ubende basement (Klerkx and Nanyaro, 1988). While the basin asymmetry and deformational style of the Ukinga sedimentary beds were recently interpreted to reflect sinistral strike-slip deformation at the origin of the Mesoproterozoic basin, sinistral transpression was identified as Neoproterozoic (Theunissen *et al.*, 1996). The Ukwama and Mbeya Range highly sheared metasediments are assumed to represent equivalents of the Ukinga Beds. In contrast with the latter, the Mbeya Range metasediments evolve inside the wrench fault zone and not along its boundary. These narrow troughs are bounded on both sides by greenschist-facies and retrograde sinistral strike-slip mylonites, locally intercalated in the basin deposits.

The Mbala Beds

The Mbala Beds trend north-northwest on an elevated ridge upon the Kate-Kipili basement. Along the eastern border, the sediments show sinistral transpressional structures which appear as reverse faulting (Theunissen *et al.*, 1996).

The Itiaso Group

The Itiaso Group sediments are intensely folded and metamorphosed. They are unconformably overlain by the only weakly deformed and non-metamorphic Bukoban Group (Halligan, 1962). The evolution of the Itiaso-Bukoba sedimentary basins along the Ubendian controlled strike-slip basins was suggested by Theunissen (1988a).

The above mentioned sedimentary basins have their deepest and most deformed parts located along the sinistral strike-slip faults, outlined by retrograde mylonites which mark the basin boundary faults. The deformational regime of the highly sheared sediments is related to sinistral strike-slip. The deformation systematically dies out away from the boundary fault zone of the basin.

The Mesoproterezoic Kibara Basin

Different from the above Mesoproterozoic basins along the Ubende Belt, the Kibara Basin developed northwest of the Ubende Belt (Figs 1 and 2A). Considering that the Kibara and Irumide Belts have comparable evolutionary trends, Klerkx and Nanyaro (1988), Daly *et al.* (1989) and Theunissen (1988b) suggested that these Mesoproterozoic orogenic belts must have originated from the reactivation of the Ubende Belt. At least the eastern Kibara Belt has been clearly demonstrated to reflect a completely intracontinental orogenic evolution and more particularly has largely preserved its extensional basin fabric (Klerkx *et al.*, 1987). A major problem in linking the Kibara evolution with the Palaeoproterozoic Ubende reactivation is the persistent sinistral strike-slip shown by the latter, while many Kibara models imply an early dextral strike-slip for creating the Kibara Basin.

In the pre-Kibara basement, structural weaknesses were created at the northwestern termination of the Ubende Belt during the Palaeoproterozoic dextral shear. In the Kibara Belt Fernandez-Alonso and Theunissen (*in press*) have shown the presence of detachment style extensional tectonics with detachment rooted to the south in a persistent sinistral strike slip zone.

Neoproterozoic sedimentary basins

Patchy distributed arenaceous Ifume, Sanyika and Mongwe Beds (not represented on Fig. 2) are considered to be Neoproterozoic. These beds are composed of very shallow sediments with weak deformational features.

Neoproterozoic sediments are more widespread along the Ubende Belt than the Mesoproterozoic sediments and they partly overlap the latter beds. They are systematically less deformed than the Mesoproterozoic sediments and are more distant from the Ubende Belt boundary. Like the Mesoproterozoic beds, they are affected by sinistral strike-slip along their northwest orientated contact with either sheared Mesoproterozoic beds or with sinistral strike-slip mylonites.

The Neoproterozoic basins are partly superimposed on the Mesoproterozoic basins. There is evidence of repeated reactivations and similar basin formation conditions all over the Proterozoic. Development of basins and their subsequent deformation is attributable to sinistral wrench faulting. This inheritance of Mesoproterozoic basins during Neoproterozoic sedimentation is also very clearly evidenced along the southern boundary of the Kibara Belt. The Mesoproterozoic rhomb-shaped basins with very shallow sedimentary and volcanic deposits originate in the reactivated external domain of the belt near the contact with its cratonic foreland (Theunissen, 1988b; Tack *et al.*, 1992).

KAROO BASINS

Karoo basins correspond with an important period of basin formation in eastern and southern Africa, from Permian to Triassic (McKinlay, 1965; Delvaux, 1991). In the Western Rift Branch this Karoo sedimentation occurs in northwest trending basins (Fig. 2C), as did their Proterozoic precursors. However two differences appear: (1) the elongate and narrow basins occur largely upon, and not along the Ubende Belt; and (2) in the south, the Karoo basins develop with a northeast-southwest trend, outside the Ubende terranes.

Karoo deposits along the northwest Ubende trend

Surface outcrops of Karoo deposits occur as isolated patches along a northwest trend in grabens and half grabens, tilted to the east (McKinlay, 1965). Karoo deposits covered a larger area than their present outcrop pattern (Figs 1 and 2C). Karoo sediments in the Rukwa

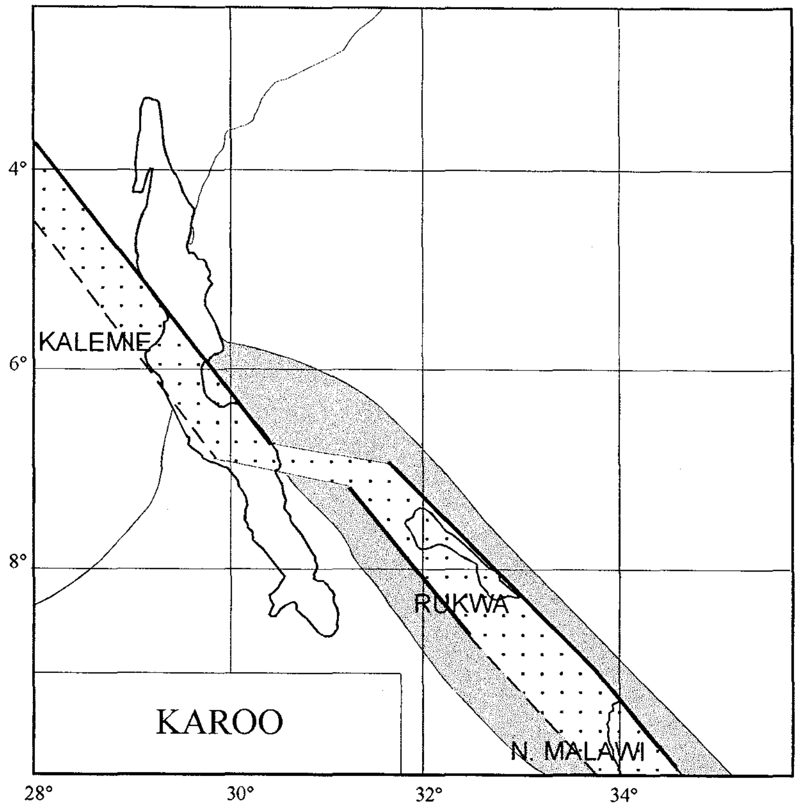


Figure 3. Karoo basins which have developed along a northwest trend and are considered to behave as strike-slip basins along northwest reactivated (inversion) Ubende Palaeoproterozoic structures.

Trough (Fig. 2C) accumulated up to 3.5 km at the base of the basin (Wescott *et al.*, 1991). They are also present in the northern Lake Malawi Basin (Specht and Rosendahl, 1989) and in the Kalemie Basin in Zaire (Cahen and Lepersonne, 1978). The Karoo event in the Kalemie, Rukwa and north Lake Malawi Troughs (Figs 2C and 3) appears as a series of deep basins flanked by Proterozoic mylonites (Rukwa and Livingstone Faults in Tanzania). Lake Tanganyika is probably underlain by Permo-Triassic sediments where that prominent fault zone crosscuts the lake (Ding and Rosendahl, 1989). These Karoo basins occur inside and along the Ubende Belt, which appears as a basement high in between the basins.

Considering the Rukwa Trough as a representative basin for the Karoo sedimentation, it is evident that the Lupa Fault acted as the main boundary fault, flanking the deepest part of the active basin, and located along the easternmost sheared sequences of the Ubende Belt (Fig. 3). Inversion of the Neoproterozoic sinistral transpression structure (Theunissen *et al.*, 1996) probably contributed to the Karoo Basin formation (Daly *et al.*, 1989). Karoo sedimentation preferentially occurred in the eastern part of the rift segment.

Other Karoo deposits

In southwest Tanzania the Karoo Beds were deposited in the Ruhuhu Basin, which lies at right angles to the Ubende trend and is close to the Usagara structure (Fig. 1). The basin contains a total of 3 km of sediments ranging from Late Carboniferous to Early Triassic (Kreuser and Markwort, 1990). The initial depocentres resulted from crustal down-warping, which was possibly associated with some faulting (Wöpfner and Kaaya, 1992). However, the main basin boundary faults developed after the deposition of the Karoo sediments and were active during the Middle Jurassic. Vertical displacements along the major faults reached up to 1000 m and tilted the sediments to the southeast (Kreuser and Semkiwa, 1987).

The Karoo Beds also occur in the poorly investigated Maniamba-Metangula Basin, which extends parallel to and more to the south of the Ruhuhu Basin (Verniers *et al.*, 1989). It is not clear whether Karoo sediments underlie the

Cenozoic beds of the Usangu flats and/or the Buhoro Trough (Marobhe, 1989).

The origin and the extension of the northeast orientated Karoo basins along the Usagara structural grain is not well documented. It is possible that the basins originated as extensional basins perpendicular to the main northwest trending strike-slip zone (Lupa-Livingstone). The Cretaceous basins in the central African shear zone in west Africa originated in a similar way (Fairhead and Green, 1989).

Geodynamic setting of Karoo basins

The Permo-Triassic deformation and associated Karoo basin formation in the Ubende Belt and adjacent areas are typical intracontinental basins which were formed due to a combination of collisional processes at the southern margin of Gondwana, and extensional processes at its northern margin.

During the Permo-Triassic period, the Pacific margin of Gondwana was in a collisional setting, while the Tethyan margin was in an extensional condition. In the present-day co-ordinates of the southern margin of Gondwana, orogenic collision occurred in the Cape Fold Belt where it generated a north-south compression during Permian-Early Triassic times (Hälbich, 1983). To the northeast, Early Permian basins developed along a north-south trend coincides with the present East Africa coast and southwestern Madagascar. These basins belong to a major rift system which was linked to a large extensional fault that penetrated deep into Gondwana, starting from its southern margin (de Wit *et al.*, 1988; Wöpfner, 1994). The northeast trending Selous Basin in southeast Tanzania marks the termination of this major marine embayment. This basin has marine fauna with a Tethyan affinity (Kreuser, 1984). Daly *et al.* (1991) revealed contractional deformation in the Central Congo Basin using seismic reflection profiles from the Cuvette Centrale. They relate this compressional deformation to other areas of east and central Africa that experienced strike-slip deformation and rifting during the Late Permian-Early Triassic.

Preliminary fault-kinematic observations and palaeostress reconstruction along the Lupa Fault, Kanda Fault and Namwele coal field, has revealed an episode of dextral strike-slip faulting along the Ubende Belt (Delvaux *et al.*, 1998). This deformation is associated to a north-south horizontal principal compression. It has affected the Permian Karoo Beds, but pre-dates the Mid-Miocene lateritic peneplain, which is well developed in this area.

In summary, the Karoo period in the Western Rift segment is characterised by two major alignments of tectono-sedimentary basins: northwest and northeast. Extension is likely to have been larger than that which is actually preserved, probably underlying the Cenozoic rift depressions. The northwest trending basins developed over the Ubende Shear Belt with their leading faults located on the most prominent Palaeoproterozoic Shear Boundary Zone (Fig. 2C). The basins probably developed in a transpressional context. The northeast trending basins developed in the Palaeoproterozoic Usagara Belt (Fig. 1) in an extensional to transtensional context.

CENOZOIC BASINS

Cenozoic rift basins in the western segment (Fig. 2D) are well outlined by the elongate and very deep lakes as Tanganyika and Malawi and by the shallow Lake Rukwa. The two deep lakes have developed outside the Ubende Belt, whereas Lake Rukwa overlies a thick sedimentary pile including the Karoo successions. Elevated basement blocks separate the Cenozoic depocentres, some of which are clearly related to basement reactivation (Theunissen *et al.*, 1996). The Buhoro Basin has developed along a northeast trend, at right angle to the northwest trending rift basins.

The Rukwa Basin

Above the 3.5 km Karoo sedimentary pile, 7.5 km of sediments accumulated in the Rukwa Basin (Fig. 2C) (Morley *et al.*, 1992) mostly of Late Cenozoic age (Westcott *et al.*, 1991; Mbede, 1993). Like the Karoo Beds, these sediments thicken towards the Lupa Boundary Fault (Dypvik *et al.*, 1990; Morley *et al.*, 1992), implying that the latter is actively involved in the recent basin formation. A recently established local seismic network in the Mbeya Range has indicated active faulting along the Lupa Fault (Delvaux and Hanon, 1993; Camelbeek and Iranga, 1996). That a large proportion of the 7.5 km Late Cenozoic sedimentary pile is of fluvial provenance is an indication that the deposition of sediments occurred in shallow water conditions over a long period. These conditions still prevail at the present time in the Rukwa Basin. This is in sharp contrast with the nearby lakes, where deep water conditions prevail.

Kilembe and Rosendahl (1992) proposed a pull-apart origin for the Cretaceous-Cenozoic Rukwa Basin. They inferred a northwest-

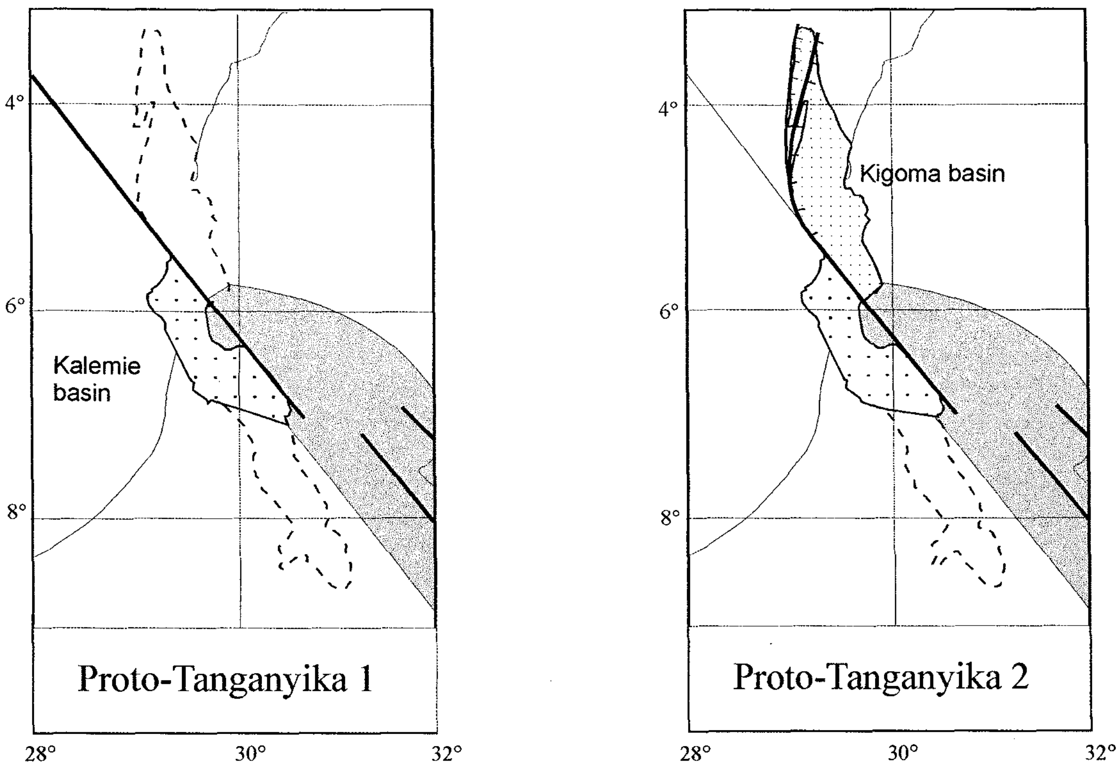


Figure 4. *Model evolutionary stages of the Tanganyika Basin. During an early stage, Lake Tanganyika started (Proto-Tanganyika 1) upon the northwest orientated Ubende Belt structure with the development of the Kalemie Basin. During a second stage the lake propagated to the north (Proto-Tanganyika 2) as a result of the reactivated (Palaeoproterozoic) horsetail (wrench fault termination), formed the north Kigoma Basin.*

southeast extensional direction for the basin. Morley *et al.* (1992) suggested a more east-west orientated principal extension stress field. Kinematic and stress analyses (Delvaux *et al.*, 1992; Ring *et al.*, 1992) made clear that the main direction of extension varied during the Late Cenozoic evolution.

In the Cenozoic rift pattern Rosendahl *et al.* (1992) proposed that the Kalemie-Rukwa-north Malawi Basins are all flanked by the main Ubendian Shear Fault Zone, and that they are down-to-the-east tilted half-grabens. The Kalemie Basin bears no water cover, the Rukwa Basin has a very shallow lake (max. 15 m) and the northern part of Lake Malawi has a water depth of up to 400 m. In between the Kalemie and Rukwa Basins (Fig. 2C) the Mahali Shoal cuts the Cenozoic Lake Tanganyika. The structure develops upon an Ubendian terrane and seismic profiling shows a complex faulted horst and graben morphology (Back, 1994). The Mahali Shoal structure had a prominent role in the evolution of Lake Tanganyika.

In the Ufipa Plateau, between the Tanganyika and Rukwa Basins, the Proterozoic mylonites in the Ubende Belt were reactivated several times (Theunissen *et al.*, 1996). They were reactivated first during the Karoo times, controlling the Namwele Coal Field (McConnell, 1946; Theunissen *et al.*, 1996; Delvaux *et al*, 1998). They were again reactivated in the Late Quaternary along the Kanda Fault, flanked by a Quaternary depocentre (Vittori *et al.*, 1997).

Whereas it is quite clear that Cenozoic active rifting processes occur along the northwest trending Ubende Belt with basins filled with very shallow water sediments, most obvious Cenozoic rift features appear as deep and elongate lakes. Most surprising these deep troughs do not overly the Palaeoproterozoic Ubendian terranes (Fig. 2D) and moreover their north-northwest regional trend is slightly oblique to the northwest trend along which the above shallow level rift basins form.

For the deep lakes Sander and Rosendahl (1989) and Specht and Rosendahl (1989) proposed a model of asymmetric half-grabens with opposite facing polarities, separated by accommodation zones as outlined by seismic profiling. However, with the same geophysical information, Morley (1988) proposed a more simple model with half-grabens as well as full grabens. Both models identified the Mahali Shoal, a northwest trending structure cross cutting Lake Tanganyika and reflecting a strike-slip deformational setting as also demonstrated by the high resolution seismic study (Back, 1994). The Mahali Shoal is a seismically active Precambrian horst (Wohlenberg, 1969) and focal mechanisms indicate extension oblique to the rift trend (Kebede and Kulhanek, 1991).

North of the Mahali Shoal, the north Tanganyika Basin enters the Mesoproterozoic Kibara domain where it is considered as a Proterozoic sinistral shear fault termination setting. The northeast-southwest trending Ubwari Shoal in the lake is considered as a basement high joining the arcuate western border fault of the Kigoma Basin (Morley *et al.*, 1990). The Cenozoic north Tanganyika Basin appears as a "horsetail" termination on a localised shear fault reactivated Ubende structure, evidenced by the Mahali Shoal.

Early stage of the Lake Tanganyika Basin

Dextral strike-slip movement along the northwest trending Mahali Fault and its horsetail prolongation toward the Ubwari is suggested to be the first tectonic control of the Cenozoic basin development in the Tanganyika area (Fig. 4). Transtensive dextral movement along the Mahali-Ubwari Fault created the Kigoma Basin as a down-to-the-west half-graben, the arcuate western border fault acting as the major fault (Proto-Tanganyika 1, Fig. 4).

However, the transfer zone between the Lupa Fault and the Mahali Fault also played a role at that time. It is obvious that the Mahali Fault has shifted to the west, compared to the Lupa Fault. The *en echelon* transfer between the two faults appears to occur through the transverse Namwele Fault Zone. This fault zone is aligned along a west-northwest trend and appears to have been active during the Karoo, as shown by small outcrops of Karoo sediments. It is consequently suggested that during the Karoo, the Rukwa Basin was joined to the Kalemie Basin by a small Namwele Basin, continuing into the present lake (Fig. 3).

During the Cenozoic, the northwest trending Lupa Fault was reactivated. To the northwest, reactivation was deflected by the Mahali Block (a massive core of less sheared Ubende rocks). The Lupa Fault then swinged to the east along the Namwele Depression in a zig-zag pattern towards Lake Tanganyika (a left stepping jump between Lake Tanganyika and Lake Rukwa; Nelson *et al.*, 1992). In this concept, the Proto-Tanganyika Basin consists of two basins (Fig. 4) separated by the Mahali Shoal. The northern Kigoma Basin is bordered to the west by the arcuate horsetail fault, a continuation of the Mahali Fault. To the south, the smaller Kalemie Basin develops as an *en echelon* pull-apart, in continuity with the Rukwa Basin. A connection possibly existed between the Kalemie and the Rukwa Basins through the Namwele transfer zone. An hydrological connection between these basins is likely to have existed during the last humid period in the Early Holocene (Delvaux *et al.*, 1998).

It is obvious that during this early stage the basin formation was absolutely controlled by the reactivated Proterozoic structures. Mechanisms were very similar to those controlling the Karoo basin development. The only difference is that the northwest trending structures were not followed over their entire length, but were deviated along the horsetail faults associated with strike-slip faults.

A similar process had already been active during Neoproterozoic. This close control of basin formation and evolution is lost during later stages of the evolution of the Tanganyika Basin.

DISCUSSION AND CONCLUSIONS

The Palaeoproterozoic Ubende Shear Belt is best considered as an early Palaeoproterozoic plate boundary outlined by deep seated ophiolite remnants which have been set in a subsequent and younger Palaeoproterozoic dextral lateral shear belt with amphibolite-facies conditions (Theunissen *et al.*, 1996). Since the Palaeoproterozoic, the shear zone has been repeatedly reactivated along northwest trending shear corridors. The repeated wrench faulting regime created different Meso- and Neoproterozoic sedimentary basins, as well as the early Phanerozoic basins. Only in the Late Cenozoic rifting did this leading control diminish, although the structure remained active.

Reactivation under different tectonic conditions resulted in three main periods of basin formation:

i) During the Meso- and Neoproterozoic, reactivation of the main northwest trending shear faults under transpressive conditions, resulted in local and isolated strike-slip related (pull-apart) basins of restricted size and relatively shallow. The major basins were formed along the outer borders of the shear belt. The Lupa Fault, corresponding to the eastern limit of the Ubende Belt, was the main active fault.

ii) The Karoo period corresponded to a major phase of basin formation in eastern and southern Africa with major reactivation of the Lupa Fault creating large basins, perfectly aligned along a northwest trend. These basins formed in accordance to the strike-slip movement along the leading fault and they are of pull-apart type. Although the major basin (the Rukwa Basin) accumulated several km of sediments, there are no indications that these sediments were deposited in deep water conditions. Tectonic conditions were transtensive all over that period.

iii) During the Cenozoic, there were deposition centers located along two major alignments. The Lupa Fault was again reactivated, with the Rukwa Basin and its southwards prolongation in the northern Malawi Basin acting as deposition centres again. Meanwhile, the northerly *en echelon* prolongation of the Lupa Fault, which was probably already active during the Karoo period, was reactivated. A northern basin formed by using the Proterozoic horsetail fault, which became the boundary fault of the still transtensive Proto-Tanganyika northern basin.

iv) During the later evolution of the Tanganyika Basin, different tectonic conditions prevailed: the narrow link between basins and basement structures was lost, the basin widened towards north and south, sometimes oblique to pre-existing structures. Sub-basins such as the northern Rusizi Basin appear to be of extensional type. Most probably during this last period the basin evolved to deep water conditions.

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