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STRUCTURAL LINK BETWEEN TANGANYIKA- AND RUKWA-RIFT BASINS AT KAREMA-NKAMBA (TANZANIA) : BASEMENT STRUCTURAL CONTROL AND RECENT EVOLUTION

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Abstract -In a WNW-ESE striking depression on the basement-high between the Rukwa and Central Tanganyika rift basins of West Tanzania, the drainage pattern of the Nkamba river testifies that during the Last Early Holocene, water drained from Lake Rukwa towards Lake Tanganyika. This connection was only interrupted in recent times. From geological maps, and supported by basement structural studies, interpretation of satellite images and a digital elevation model of the region, the close structural relationship between the rift and the Palaeoproterozoic Ubende belt is highlighted. The NW striking rift roughly follows the regional buildup of the Palaeoproterozoic Ubende belt, particular structures of which were repeatedly reactivated and became inherited in todays rift morphology. This also applies for the basement structures under the WNW-ESE trending Nkamba-Karema depression, where eclogite remnants show that the Palaeoproterozic Ubende belt is involved as a suture. The WNW trending flexure and its reactivation features confirm the close control of the Ubende belt's structural characteristics on the Phanerozoic rift evolution: the Rukwa rift developed upon the regional NW Ubende suture, and is linked to the Central Tanganyika (-Kalemie) rift through the WNW flexure in the suture, controlling the Karema-Nkamba rift depression. Recent tectonic activity along the NW Rukwa trend may have triggered the closing of the WNW-ESE Nkamba-Karema flexure.

Keywords : Palaeoproterozoic, Ubende belt, Ubende suture, recent rift, inheritage, Tanzania, DEM

1. INTRODUCTION

As is common for continental rifts, the western branch of the East African Rift System in western Tanzania (Fig. 1a) avoids the Archaean craton and preferentially, although not exclusively, extends along the regionally NW trending Ubende Palaeoproterozoic belt. To what extent and how the latter controls the rift evolution in western Tanzania may be debated, and distinguishing rift structures from basement reactivation structures is often controversial (Rosendahl, 1987). It is however obvious that the introduction of a 'Pan-African Rukwa belt' in a critical area of the west Tanzanian rift, as proposed by Pinna (1995), is to our view at the least misleading studies of the Precambrian basement in the area. When recent rift papers moreover refer to a 'Pan-African' crystalline basement along the Rukwa basin (Morley *et al.*, 2000), the role of basement structures in the rift become even less understandable.

Basement structural studies in the west Tanzanian rift region (Theunissen *et al.*, 1996) confirmed previous work (McConnell, 1980; Daly, 1988; Sutton and Watson, 1986) and claim that the NW striking Palaeoproterozoic Ubende belt exerts a leading structural control (Chorowicz

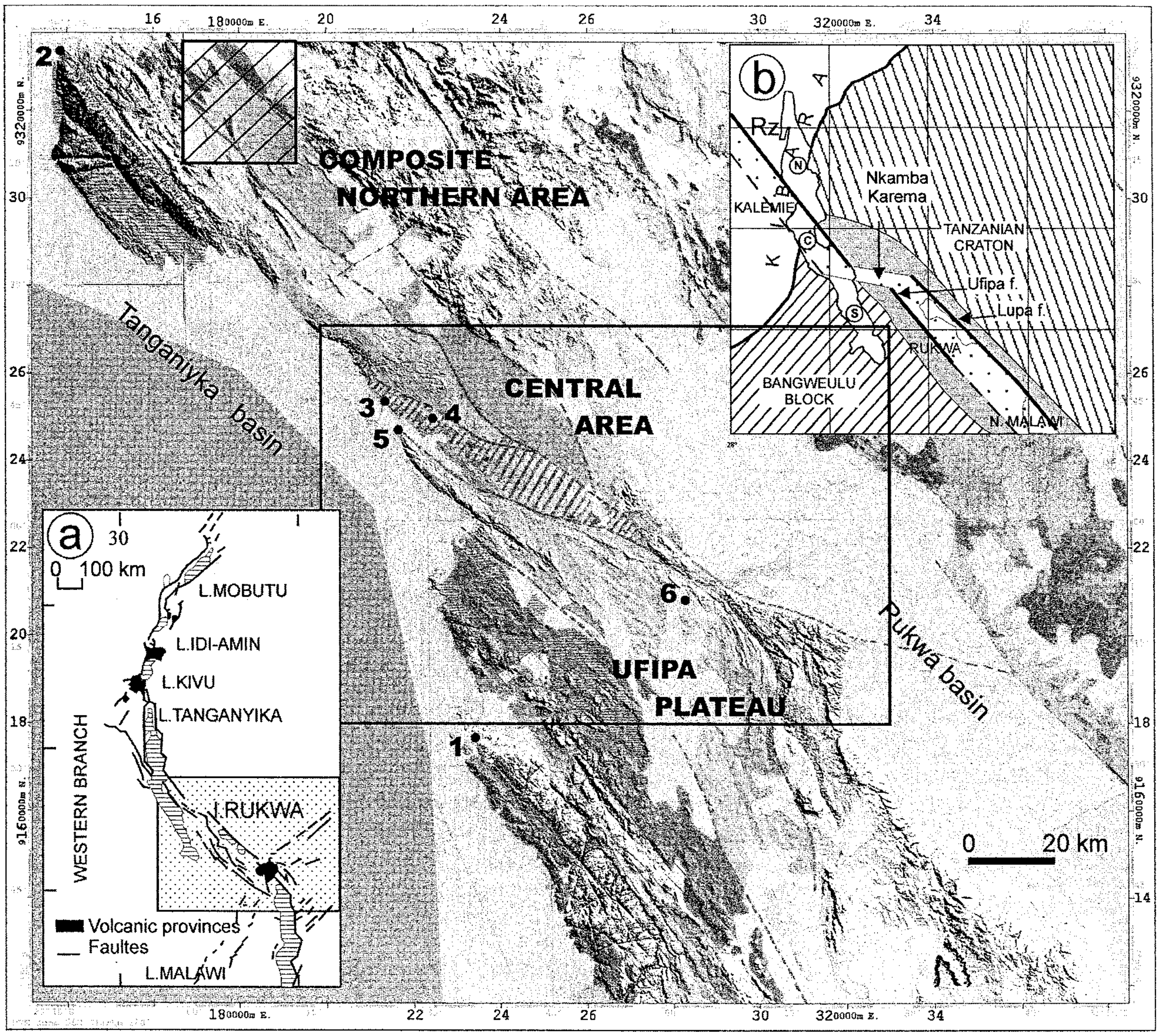

Fig. 1. - Combined 30 m resolution (in longitude, latitude) digital elevation model (DEM) and grey-scale transposition of basement geology (after Smirnov *et al.*, 1973) of the northern Ubende belt in West Tanzania. The DEM was specially processed to enhance structural information embedded in the present-day topography (hill-shading).
Central square corresponds to area of Fig.4. Hatched-out area indicates missing data in DEM
Position of localities cited in text: 1. Kipili; 2. Pasagulu; 3. Ikola; 4. Kapalamasenga; 5. Karema; 6. Chisi
Insets :
a. Location of the area in the western rift branch. Shaded area corresponds roughly to inset b.
b. Schematic outline of the WNW-striking Karema-Nkamba as structural link between NW-striking Kalemie- and Rukwa basins in Karoo (after Klerkx *et al.*, 1998).
Central Tanganyika (C) - and Rukwa basins with assumed Karoo remnants in the WNW striking Nkamba-Karema area all occur on, or are flanked by, Ubende- or 'Rusizian' (Rz) terranes. At a weak angle to the NW trending Karoo basins, the younger North (N) and South (S) Tanganyika basins are flanke by respectively the Mesoproterozoic Kibara fold belt and by the Late Palaeoproterozoic Bangweulu block.

et al., 1988; Klerkx *et al.*, 1998). In support of this, this paper first reviews the main characteristics of the Palaeoproterozoic Ubende belt to provide better insight in the close parallelism between Palaeoproterozoic Ubende basement fabrics and the multiphase Phanerozoic rift geometry. This parallelism is lacking for other, non-Ubende Palaeoproterozoic basement, as is for example the case for the south Tanganyika rift basin (Rosendahl, 1987). Most basement structural studies also report the frequent expression of particular basement characteristic features in many parts of the present or recent rift morphology.

For this paper, the Tanzanian 1/50.000 topographic maps covering the whole west Tanzanian rift zone have been digitized. A 30m-resolution (x, y) digital elevation model (DEM) of the northern part is presented with an overprinted geological map (compiled from Smirnov *et al.*, 1973; Fig. 1).

The paper discusses that in the northern Ubende belt, the WNW-ESE striking Karema-Nkamba depression of the present rift morphology, although at an angle to the adjacent NW striking Rukwa and central Tanganyika rift basins (Fig. 1b), also reflects Ubende belt characteristics. The basement of this WNW Karema-Nkamba depression shows similar settings and structural weaknesses as the basement flanking the NW Rukwa basin (Fig. 1). Tectonic activity along NW-oriented basement structures is well documented for the Lupa fault, bounding the Rukwa basin (Morley *et al.*, 1999; 2000) and for the Kanda fault on the Ufipa plateau (Delvaux *et al.*, 1998). In the present NE-SW to ENE-WSW extension (Foster and Jackson, 1998) this accomodation along NW-striking basement weaknesses probably had consequences for the WNW-ESE striking Nkamba-Karema structure, confirming the important role of the zone as the structural link in the Ubende controlled Tanganyika-Rukwa rift evolution (Fig. 1b after Klerkx *et al.*, 1998).

2. CHARACTERISTICS OF THE BASEMENT STRUCTURAL WEAKNESSES

Different categories of basement weaknesses can be identified all over the West Tanzanian rift zone. For a large part they also occur in the northern part of the Ubende belt (Fig. 2) and they can be summarized as drawn on a schematic W-E section (Fig. 3) across the dominant NW striking oblique accretional belt. In this cross section, the Palaeoproterozoic suture (Klerkx *et al.*, 1997) along the Archaean craton (1) is composed of different terranes. Early stage (2) granulite facies Ubende rocks (2100- 2025 Ma, Lenoir *et al.*, 1994) include Palaeoproterozoic eclogite remnants (Sklyarov *et al.*, 1998) and exhumed at ca. 1848 Ma (Boven *et al.*, 1999) during a second stage (3) amphibolite-facies lateral shear deformation (1950-1850 Ma, Lenoir *et al.*, 1994). The second stage deformation overprints early exhumation structures of the early-stage granulite- and eclogite-bearing terranes and it forms the main and characteristic NW striking ductile structure in the felsic gneisses with regional upright folding. During this second stage deformation many terrane boundaries (II) were enhanced as ductile shear zones. The steeply dipping terrane boundaries and locally also the steep limbs (IV) of the ductile folds were reactivated by younger Proterozoic and greenschist-facies sinistral strike-slip mylonites, contrasting with the earlier ductile fabrics.

Different from these Ubende terranes, late Palaeoproterozoic volcano-plutonic rocks (Kate and Kipili terranes; Ka & Ki on Fig.2) and younger Mesoproterozoic Mbala sediments (Mb on Fig.2), do not display the characteristic ductile lateral shear deformation. These sequences form part of the Bangweulu block (4) from eastern Congo and Zambia and constitute the Precambrian basement outcropping around the South Tanganyika rift lake.

There is thus no Neoproterozoic or Pan-African orogenic event recorded in the Rukwa-Tanganyika basement, which is exclusively Palaeoproterozoic with two distinct settings. These consist of weakly or almost undeformed, predominantly late magmatic rocks of the Bangweulu block to the west and the older Palaeoproterozoic Ubende belt terranes, all laterally accreted along NW trend to the Archaean craton in the east.

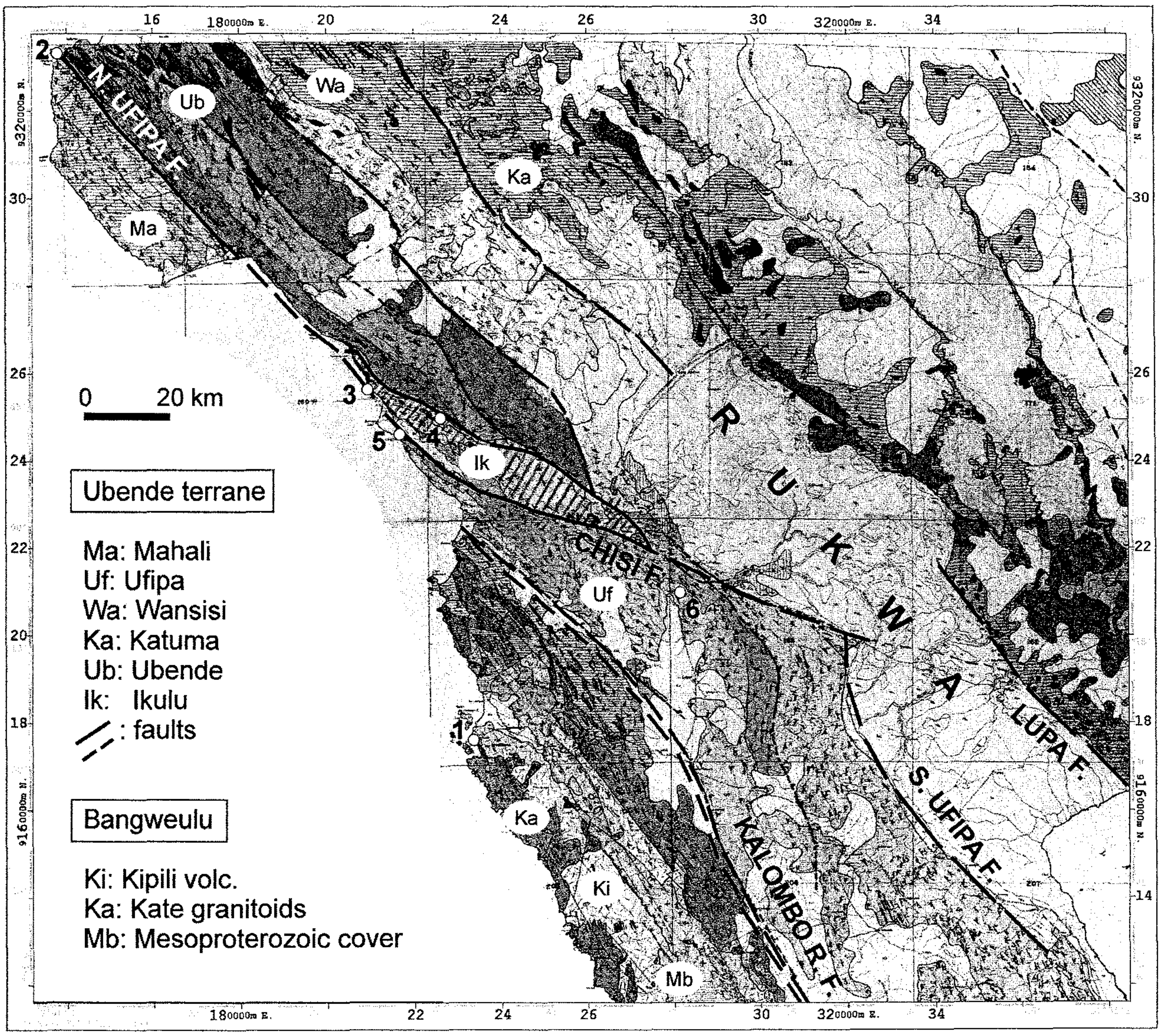

Fig. 2. - Geological map of the northern Ubende belt in West Tanzania (after Smirnov *et al.*, 1973) with principal terranes and structures enhanced and simplified.
Position of localities cited in text: 1. Kipili; 2. Pasagulu; 3. Ikola; 4. Kapalamasenga; 5. Karema; 6. Chisi

Fig. 3. - Simplified schematic W-E cross section of the Ubende belt enhancing its fundamental structural characteristics. A Palaeoproterozoic suture (I) occurs between the Archaean craton (1) and the Ubende belt (2-3) which is flanked in the West by the Bangweulu late Palaeoproterozoic magmatic block (4). In the Ubende belt the composite early-stage (2) terranes (including HP-granulite remnants) and the second-stage (3) amphibolite-facies terranes are separated by steeply inclined and shear-faulted boundaries (II) also marking the western boundary (III) of the Ubende fold belt as well as its steeply inclined fold limbs (IV).
Many of the Palaeoproterozoic shear faults have been repeatedly reactivated and some are clearly enhanced in the present rift morphology, corresponding respectively to I= Lupa-, II= Ufipa-, III= Kalombo river- and IV= Kanda-faults.

3. BASEMENT GEOLOGY AND MORPHOLOGY IN THE NORTH UBENDE BELT

On the geological map of the northern part of the Tanzanian Ubende belt (Figs. 1 and 2) different metamorphic terranes can be distinguished and often are juxtaposed along NW striking fault zones, confirming previous work in the area (McConnell, 1967; Sutton *et al.*, 1954). Later structural (Theunissen *et al.*, 1996), metamorphic (Sklyarov *et al.*,1998) and geochronological studies (Lenoir *et al.*, 1993, 1994; Boven *et al.*, 1999) in that region were mainly carried out in the western part of the belt.

To what extent basement geology is also expressed in the present morphology is outlined on the combined geological map and shaded digital elevation model (Fig. 1). The basement high, separating today the Tanganyika rift lake in the west from the northern end of the Rukwa basin in the east, appears with three main different morphologies. A northern composite area with NNW to NW trending alternating lows and highs, a central WNW-ESE depression of Karema-Nkamba and a southern plateau (Ufipa plateau) with a NNW to NW trending and weakly contrasting morphology. These morphologies also appear in the detailed DEM image, covering the Nkamba-Karema region (Fig. 4).

3.1. The Southern (Ufipa) Plateau

The NW elongate Ufipa plateau consists of Ufipa felsic gneiss (second stage terranes, Fig. 3) with NW to NNW trending upright folds with gently plunging fold axes. A main antiformal fold closure at the northern extremity of the plateau is curving WNW, parallel with the Chisi shear fault zone (Figs. 2, 4 and 5). At the eastern Ufipa plateau boundary the Ufipa rift shoulder is obvious (Fig. 4) and is partly associated with the westward tilting of the plateau along the Ufipa terrane boundary fault (Figs. 1, 2 and marked II on Fig. 3), flanking the Rukwa basin. To the south and out of the area (not shown on Fig.s) a sinistral strike-slip mylonite reactivation zone develops along the Ufipa terrane boundary fault, separating the granulite-bearing mafic-ultramafic Mbozi terrane (stage one terrane) from the Ufipa terrane. Also the Kanda rift fault (schematically represented as IV in Fig. 3) inside the Ufipa plateau overlies sinistral strike-slip mylonites that formed in a steeply inclined fold limb in Ufipa gneiss. Like the Ufipa terrane boundary fault, the active Kanda fault fits in the westward tilting of the Ufipa plateau (Theunissen *et al.*, 1996; Delvaux *et al.*, 1998). On this plateau, the Kalombo river fault zone (Fig. 2 and represented as III on Fig. 3) locally enhances the boundary between the Ubende belt and the Bangweulu block with its Meso- or Neoproterozoic undeformed Mbala sandstone, unconformably

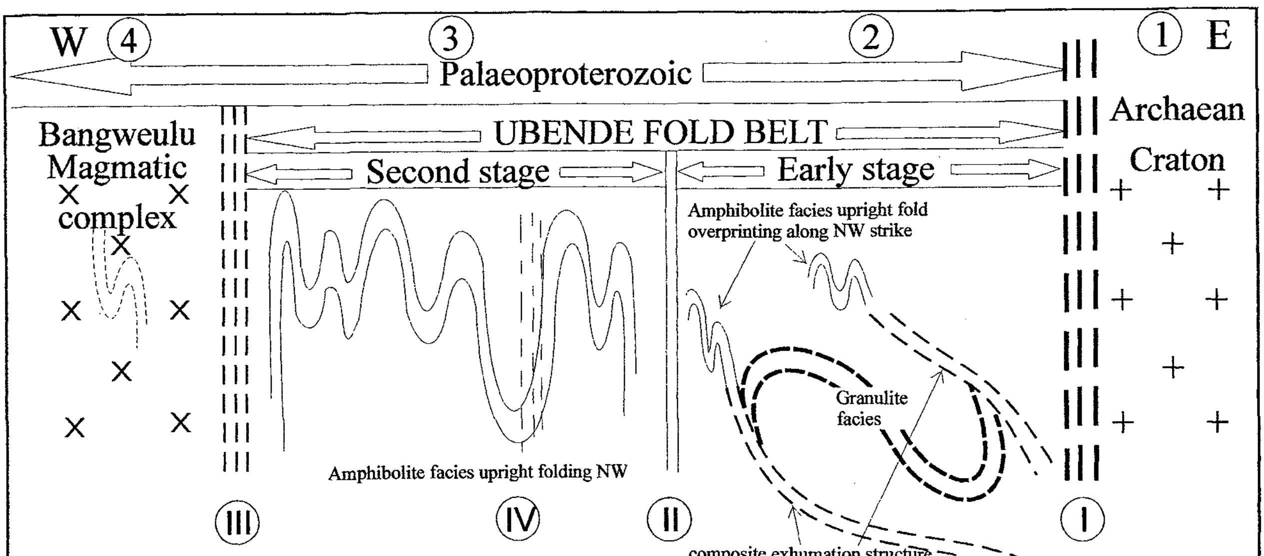

Figure 3

overlying the unsheared late Palaeoproterozoic Kate-Kipili volcano-plutonic complex. Not affected by the ductile Ubende Palaeoproterozoic shear deformation, this part suffered only local effects of sinistral strike-slip reactivation in adjacent Ufipa gneisses. The sequences of the Bangweulu block, surrounding the south-Tanganyika basin, occur up to Kipili (point 1, Fig. 1). From Kipili to the north, the Kate granites, intruding and alternating with Ufipa-equivalent Mahali gneisses, strongly show retrograde sinistral strike-slip.

3.2. The Northern composite (Ubende) mountain range

The different metamorphic terranes (Figs. 1 and 2) appear with contrasting morphology in the western part, where the Mahali gneisses (considered as an equivalent of the Ufipa gneissic terrane) mark an elevated horst-like relief flanked by a relative lower-level plateau of Ubende mafic rocks. More to east the Wansisi Al-rich metasediments occur. These three terranes are juxtaposed along NW to NNW striking boundary faults. The Ufipa and Mahali gneisses are both predominant felsic rocks and contrast with the adjacent predominant mafic and ultramafic Ubende and Ikulu rocks. Along their NW trending boundary both mafic and felsic terranes are intensely affected by sinistral lateral sheared mylonites (represented as II on Fig. 3), which are parallel with the NW to NNW trend of the steeply inclined folding and associated foliation in the felsic terranes. Eclogites and their Palaeoproterozoic exhumation Ar/Ar age were identified at Pasagulu (point 2 on Figs. 1 and 2) along the NW boundary between mafic and felsic terranes. From Ikola (point 3 on Figs. 1 and 2), with mafic-ultramafic layered complex until Kapalamasenga (point 4 on Figs. 1 and 2), with metacherts, remnants of the Palaeoproterozoic ophiolite are exposed in the Ikulu terrane. As a main NW striking boundary between the composite mafic-ultramafic Ubende-Ikulu-Mbozi terranes and felsic Ufipa-Mahali terranes, the Ufipa shear fault zone (Figs. 1 and 2 and represented as II on Fig. 3) is exposed east of the Ufipa plateau (southern Ufipa fault, Fig. 2) and in the western extremity of the composite northern part (northern Ufipa fault, Fig. 2).

3.3. The WNW-ESE Karema-Nkamba depression

The most prominent structure is the southern boundary of the depression extending SSE as an almost continuous ridge from Karema (point 5 on Figs. 1 and 2), over Chisi (point 6 on Figs. 1 and 2) up to the Ufipa fault zone in the east (Figs. 1, 2 and 3). Elongate lenticular hills (Fig. 4) along the ridge are sinistral strike-slip mylonites, locally exhibiting rift-related dextral reactivation (Chorowicz *et al.*, 1988). Mylonitic rocks of mainly felsic composition also include mafic lenses and eclogites at Chisi (point 6 on Figs. 1 and 2). The ridge is considered as the WNW-ESE link (central Ufipa fault, Fig. 2) between the NW striking northern and southern part of the Ufipa-terrane boundary fault-zone between mafic and felsic terranes (Figs. 3 and 4). Inside the Karema-Nkamba depression the DEM (Fig. 4) shows the remarkable coincidence of particular basement features and morphology. The Ikola-Kapalamasenga ridge between the ophiolite-bearing Ikulu terrane and the Ubende terrane, bears a series of carbonatite complexes of unknown age. Along the Ifume valley east of Karema, an elongated area is composed of unmetamorphosed and weakly SW inclining arenaceous beds which unconformably overly the Ubende belt. Their age is unknown but both Neoproterozoic and Karoo ages were proposed in literature (McKinlay, 1965). Structural interpretation of Landsat TM imageries of the basement in the Karema-Nkamba depression suggests that its complex build-up corresponds with a duplex structure (Fig. 5).

4. THE KAREMA-NKAMBA BASEMENT FLEXURE IN THE NW-SE RIFT

The WNW-ESE trending sinistral strike-slip mylonite ridge of Karema-Chisi (Chisi fault, Fig. 2) has been proposed to have been preferentially reactivated in Neoproterozoic (Theunissen *et al.*, 1996), after the Palaeoproterozoic eclogites exhumed in complexely structured amphibolite-facies composite exhumation fabrics. It is considered to be associated with a large flexure (Figs. 2 and 5) in the NW Paleoprotereozoic suture. In the structural context, the Ifume

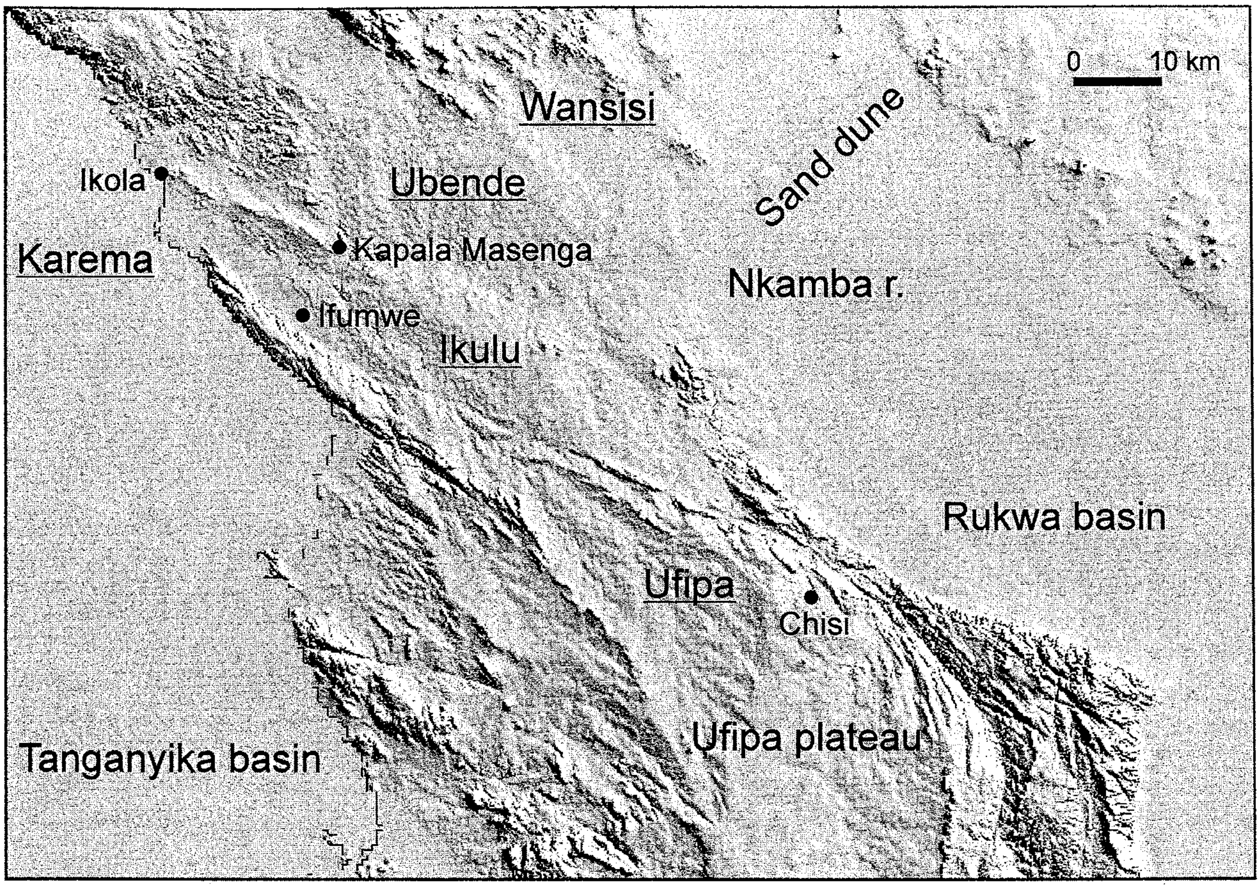

Fig. 4. - Digital Elevation Model of the central part of the study area, specially processed to enhance structural information embedded in the present-day topography. The WNW striking Nkamba-Karema depression is clearly forming on the basement high between the South Tanganyika basin and the Rukwa basin.

sediments, Neoproterozoic according Smirnov *et al.* (1973), do not correlate with Mbala sandstones which overly late Palaeoproterozoic and unsheared Kate-Kipili basement rocks. Ifume is here understood as a remnant Karoo deposit, somehow associated with the Central Tanganyika-Kalemie early rifting (Fig. 1b after Klerkx *et al.*, 1998).

From Pasagulu in the north over Karema and Chisi (points 2, 5 and 6, Fig. 1) and up to Tunduma in the south (outside the area), the boundary between mafic (Ubende, Ikulu, Mbozi) and felsic (Ufipa, Mahali) terranes appears with a similar sharply outlined Ufipa fault scarp morphology (Figs. 1, 2 and 4). Accomodation of the structure on varying stress field conditions is probably not homogeneous but it is hardly acceptable that tectonic activity should be restricted only to the Rukwa segment (Fig. 1b).

In the southern Rukwa seismic network (Camelbeeck and Iranga, 1996) only little seismicity appears above 10-12 km, while 20% of the earthquakes occur in the 12-14 km zone, and earthquake intensity decreases down to a depth of 34 km. Foster and Jackson (1998) recorded recent earthquake events with 10 and 25 km deep epicenters and with normal motion indicating NE-SW to ENE-WSW extension. In these conditions the steeply inclined Palaeoproterozoic weaknesses in the basement may reactivate. The Kanda fault (south of the study area) is an active normal fault (Delvaux *et al.*, 1998) associated with westward tilting of the Ufipa plateau, also responsible for the formation of the Ufipa shoulder along the Rukwa basin. The Ufipa rift-related tilting occurs on steeply inclined NW to NNW striking Ubende structures on which the Karema-Nkamba mylonites are tied (Theunissen *et al.*, 1996).

A particular weak zone in the Rukwa rift is the Lupa rift fault zone along the contact between the Ubende belt and the Archaean craton. In the Rukwa basin itself, Pliocene-Holocene high frequency cyclic fault activity of the Lupa fault is evidenced by high-resolution seismic studies (Morley *et al.*, 2000).

Independent from, and unrelated with any basement structure, traces of a palaeo-Nkamba river outlet (Fig. 4) from lake Rukwa to lake Tanganyika were recently interpreted to reflect Late Quaternary tectonic activity (Delvaux *et al.*, 1998) along the WNW-ESE Karema-Nkamba depression. Todays isolation of the Nkamba-Karema depression from the north Rukwa basin can be associated with the westward active tilting of the Ufipa block inducing recent accomodation along the Chisi boundary fault.

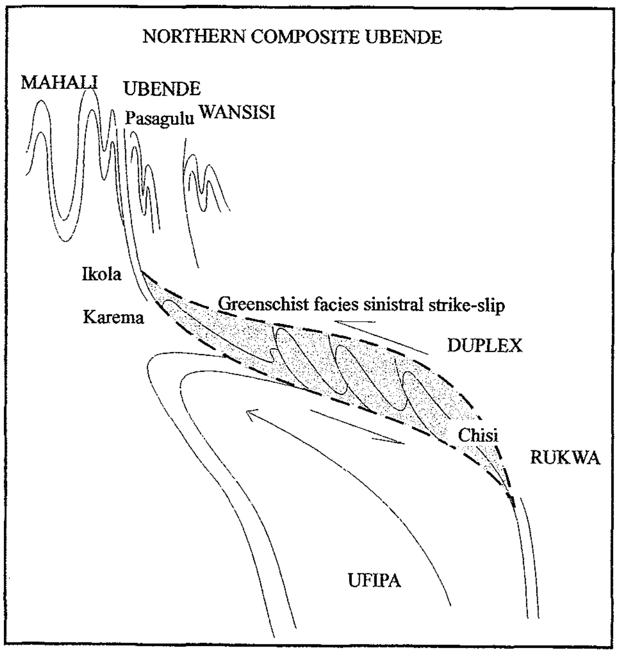

Fig. 5. - Interpretative and idealized cross section and plan representation, showing the WNW-ESE flexure in the basement structure underlying the Karema-Nkamba depression (Fig. 4). Explanation in texte.

5. DISCUSSION AND CONCLUSIONS

Nowhere in the basement of this part of the rift segment, a Pan-African orogenic event was recorded and only Neoproterozoic structural reactivation of pre-existing Palaeoproterozoic structures are identified. The relationship between Phanerozoic NW-oriented rift and Palaeoproterozoic basement appears at different orders of magnitude :

- deep NW-oriented basins with Karoo deposits overly the NW-striking Ubende shear belt (Rukwa - Central Tanganyika – Kalemie on Fig. 1b);
- the contact zone between the Ubende belt and the Archaean craton reactivated as the Lupa fault, the main boundary fault of the Rukwa rift basin (Figs. 1 and 2, represented as I on Fig. 3);
- inter-terrane boundary shear faults (represented as II on Fig. 3) reactivate as morphological fault scarps (Ufipa), locally flanking rift basins;
- intra-terrane shear faults (represented as IV on Fig. 3) exist along steeply inclined ductile fold limbs (represented as IV on Fig. 3).

The reason for insisting on the Ubende belt and its Palaeoproterozoic age instead of a Pan-African basement for the Tanganyika - Rukwa rift segment in the area is the very particular ductile shear character, belonging to an oblique accretional setting that includes eclogites and thus reflects a paleosuture along the Tanzanian craton. Since Palaeoproterozoic times these structures have been involved in repeated strike-slip deformational accomodation of the East-African lithospheric segment, that is weakened along them (Theunissen *et al.*, 1996). The Phanerozoic rift is controlled by these lubricated Palaeoproterozoic structural weaknesses (Daly *et al.*, 1989).

In the Tanganyika-Rukwa rift segment the jump between Rukwa and Tanganyika (Fig. 1b) is of particular interest in understanding the rift evolution (Klerkx *et al.*, 1998 and references there in). Only the Central Tanganyika basin is flanked by the NW-oriented Ubende belt. That part extends along a NW trend into Congo, where the Kalemie rift basin (Fig. 1b) is flanked by enigmatic Rusizian (Rz on Fig. 1b) of postulated Palaeoproterozoic age (Cahen *et al.*, 1984). The Kalemie and Rukwa rift basins have many common evolutionary characteristics with this Palaeoproterozoic NW sheared basement, (Klerkx *et al.*, 1998; Delvaux *et al.*, 1998). In contrast, the large southern Tanganyika basin (Fig. 1b) is completely surrounded by late Palaeoproterozoic rocks (Bangweulu with the Kate-Kipili complex in Tanzania) which do not show the particular structural characteristics of the Ubende belt (Theunissen *et al.*, 1996).

The WNW Karema-Nkamba zone overlies a major switch in the Palaeoproterozoic Ubende suture and is flanked by Proterozoic strike-slip reactivation mylonites, weakening the ductile basement structure. These mylonites became rift reactivated as the WNW Chisi fault, separating the NW striking Ufipa terrane in the Ufipa plateau from the eclogite bearing mafic-ultramafic Ubende-Ikulu terranes forming a depression. As a major terrane boundary fault, the WNW striking Chisi rift fault must somehow link with the NW striking Rukwa structures, including the Lupa rift fault.

Recent tectonic activity along the NW striking Rukwa and adjacent Ufipa is recorded along reactivated steeply inclined Palaeoproterozoic structures, affecting the Pliocene-Holocene uppermost Rukwa sediments (Morley *et al.*, 2000) and tilting the Ufipa plateau to the west (Delvaux *et al.*, 1998). The Digital Elevation Model of the northern Ubende belt highlights the controlling character of Palaeoproterozoic basement structures on the recent rift architecture, as outlined by coinciding morphological features and reactivated Palaeoproterozoic basement structures.

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