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Karoo rifting in western Tanzania: precursor of Gondwana break-up?

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ABSTRACT. The Karoo basin system in the NW-trending Ubende Belt in Tanzania and East Congo is a manifestation of the early stage of Gondwana break-up in East-Central Africa. The Karoo tectonic evolution of the Tanganyika-Rukwa-Malawi (TRM) zone in the East African rift was re-evaluated. A new model of evolution for the Karoo period (Late Carboniferous - Triassic) in the Ubende belt is presented. Instead of a former model of transcurrent basin formation in transtensional setting, an evolution in three successive tectonic stages is proposed. Karoo basins, much larger than the remaining ones, formed initially as a result of tectonically controlled subsidence during the Late Carboniferous - Permian and were filled by fluvial-deltaic to lacustrine sediments. Along the Ubende belt, they probably formed two major basin systems: the Kalemie - Lukuga - South Tanganyika (KLT) and the Rukwa - Songwe - North Malawi (RSM) troughs. Karoo sedimentation in the Ubende belt ended by Late Permian-Early Triassic transpressional inversion which caused strike-slip dislocation and tilting of the basins, particularly well observed in the Namwele-Mkomolo coalfield and also reported for the Congo basin (Cuvette centrale). In the NE-trending Karoo rift basins of Zambia and southeast Tanzania it caused a sedimentation gap and slight unconformities. This transpressional inversion is a good indication that intraplate compressional deformation was transmitted to the foreland of the palaeo-Pacific active margin of Gondwana during the Permo-Triassic transition. The tectonic inversion had a relatively short duration and was followed by a long period of regional uplift and denudation in the Ubende belt during the Triassic-Early Jurassic, with formation of the "Gondwana" morphological surface. In southeast Tanzania, sedimentation continued, probably until Early Jurassic times, prefiguring the future crustal failure between Western and Eastern Gondwana.

Keywords: Karoo, Rifting, East Africa, Tectonic evolution, Gondwana.

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1. Introduction

Continents often break-up parallel to ancient orogenic belts (VAUCHEZ *et al.*, 1997). The easiest way to initiate the breaking up of continents is to reactivate long-lived crustal scale weakness zones by transcurrent movements. It is well known that the Cenozoic rift basins of the East African rift in East Africa are generally superimposed on Paleoproterozoic mobile belts surrounding the Tanzanian craton (MCCONNELL, 1972). They formed mostly by extensional processes, but largely reactivated older basin systems. In the Ubende belt, along the western margin of the Tanzanian craton, sedimentary basins formed as early as in the Mesoproterozoic, apparently in a strike-slip context (KLERKX *et al.*, 1998).

The Tanganyika-Rukwa-Malawi (TRM) segment of the East African rift is a good example of a long-lived weakness zone that was repeatedly reactivated, even after long periods of tectonic quietness. It was shown (DELVAUX, 2000) that the Permo-Triassic Karoo rift system developed in response to intraplate transpressional deformations induced by stress transmission from both the southern (Paleo-Pacific) and the northern (Neo-Tethys) margins of the Gondwana continent. In this context, the Karoo rift system in western Tanzania is a precursor of the late Cenozoic rifting.

This work will review the available evidence for the development of a series of Karoo basins in the Ubende belt and their subsequent deformation. It will be based on existing data from the literature and geological maps, on the interpretation of satellite images and a new digital elevation model (DEM) of the Ubende belt, produced at the Royal Museum for Central Africa from 1/50.000 topographic maps. This will be supplemented by field structural observations and results of paleostress analysis of minor fault data collected in the field.

2. Tectonic setting

During the Late Paleozoic to recent times, the TRM segment of the western branch of the East African rift system was affected by repeated rifting cycles (MCCONNELL, 1972). The western rift branch displays a sigmoidal geometry and is superimposed on the Proterozoic mobile belts, which surround the Archean Tanzanian craton (Fig. 1). In particular, the North Malawi, Rukwa and South Tanganyika rift basins developed in the NW-trending Ubende belt, defined by QUENNELL *et al.* (1956) and MCCONNELL (1950). The TRM zone shows evidence of Permo-Triassic and Late Mesozoic and/or Early Tertiary rifting, prior to a major Late Cenozoic rifting cycle (DELVAUX, 1991, 2000; MBEDE, 1993; DELVAUX *et al.*, 1998; VAN DER BEEK *et al.*, 1998).

The Rukwa rift basin (PEIRCE & LIPKOV, 1988) is located in the relay zone between the Tanganyika and Malawi (Nyasa) rift valleys (Fig. 1), which together form the NW-trending Tanganyika-Rukwa-Malawi (TRM) lineament. The TRM lineament is interpreted by KAZMIN (1980), CHOROWICZ & MUKONKI (1980), TIERCELIN *et al.* (1988) and WHEELER & KARSON (1994) as an intracontinental transform fault zone, along which the Rukwa rift basin opened as a pull-apart basin in response to oblique, NW-SE extension. In contrast, MORLEY *et al.* (1992) favour an opening of the Rukwa rift basin in a NE-SW direction, sub-orthogonal to its general trend. Also SANDER & ROSENDAHL (1989) and SPECHT & ROSENDAHL (1989) suggest a sub-orthogonal opening of the Tanganyika and Malawi rift basins.

All these models generally do not consider explicitly the possible existence of older rift basins along the TRM trend, although their occurrence has been demonstrated. They largely influenced the geometry and location of the Late Cenozoic rift basins by the classical process of tectonic reactivation. It was shown recently (DELVAUX, 2000) that the NW-trending Ubende belt is a zone of repeated reactivations since the Palaeoproterozoic, controlling successive stages of sedimentary basin formation.

In the Palaeoproterozoic, the Ubende shear belt formed by right-lateral oblique convergence with subduction under the western margin of the Tanzanian Archean craton (LENOIR *et al.*, 1994;

THEUNISSEN *et al.*, 1996; SKLYAROV *et al.*, 1998). Left-lateral movements in retrograde greenschist facies reactivated the NW-trending Ubende belt during the Meso- and Neoproterozoic (THEUNISSEN *et al.*, 1992), controlling the development of a series of pull apart-type sedimentary basins (KLERKX *et al.*, 1998).

During the Late Carboniferous - Permian, NW-trending Karoo rift basins developed in response to compressional and transpressional deformations in East-Central Africa. Recent works (DAMBLON *et al.*, 1998; DELVAUX *et al.*, 1998; VAN DER BEEK *et al.*, 1998) suggested the probable existence of an Early Tertiary rifting stage. The Late Cenozoic rift system in the Rukwa-Malawi area started 8-9 Ma ago by semi-radial extension and evolved locally to strike-slip deformation since the mid-Pleistocene (DELVAUX *et al.*, 1992; RING *et al.*, 1992; DELVAUX & HANON, 1993).

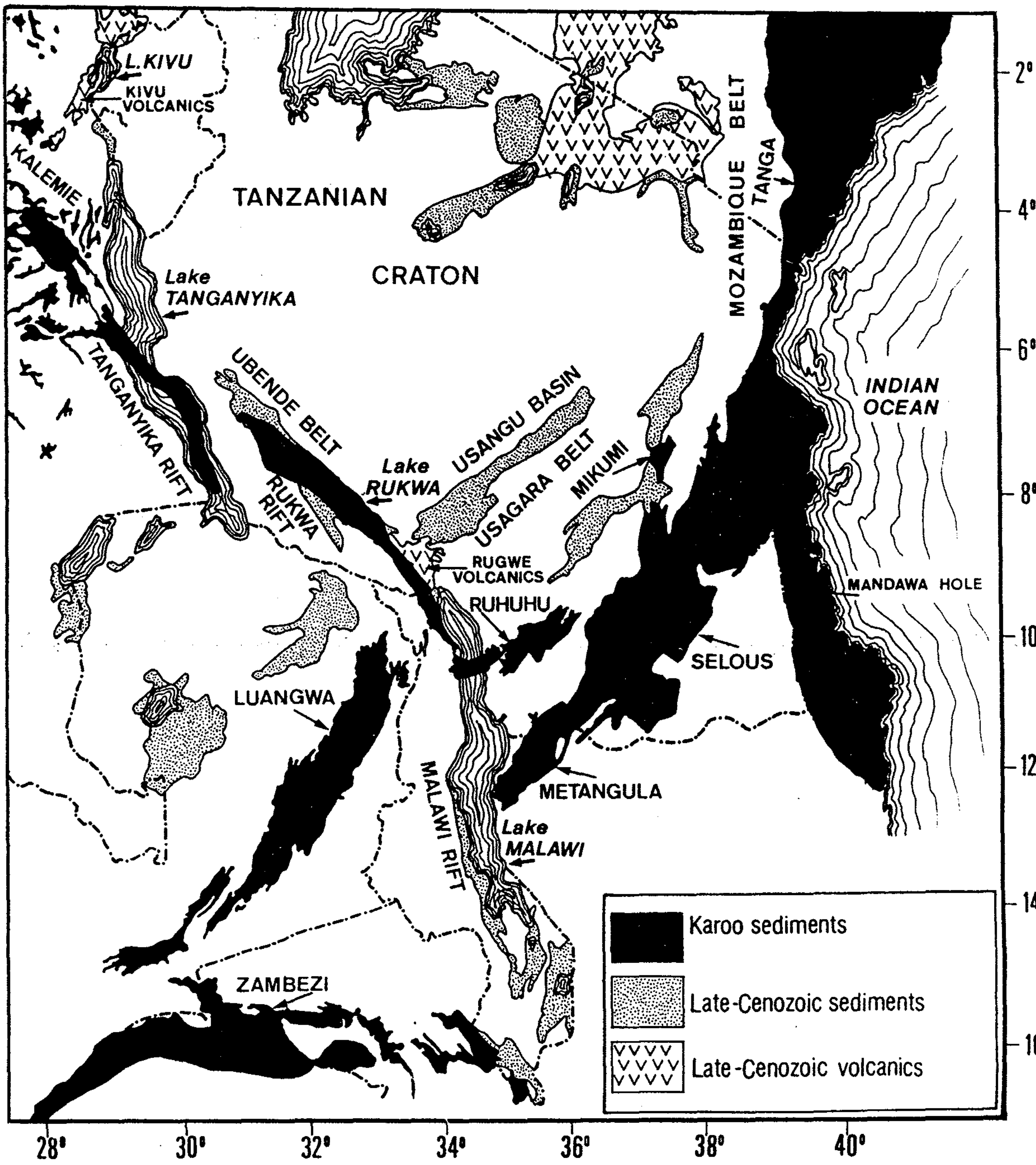

Fig. 1: Karoo and Cenozoic rift depressions in southern East Africa (modified after VERNIERS *et al.*, 1989 and DELVAUX, 1991).

3. Karoo sedimentation and tectonics

During the Late Carboniferous to Early Triassic times, the area of the future East African rift in East Africa was affected by the formation of Karoo rift basins along two orthogonal trends, that are characterized by different histories (KLERKX *et al.*, 1998; DELVAUX, 2000).

3.1. NE-trending Late Carboniferous-Triassic basins

A major system of Karoo rift basins developed along a NE- trend. It includes the Zambezi and Luangwa basins in Zambia (UTTING, 1976; NYAMBE & UTTING, 1997), the Ruhuhu and Metangula basins on the eastern side of the Lake Malawi (WOPFNER & KAAYA, 1992; VERNIERS *et al.*, 1989), the Kilombero and Selous basins in East Tanzania (WOPFNER & KAAYA, 1991; NILSEN *et al.*, 1999), the Tanga basin in East Kenya and the Malagasi basin in West Madagascar (Figs. 1 and 5). All these basins contain a relatively complete stratigraphic succession, ranging from Late Carboniferous to mid-Triassic (or even Early Jurassic in the Luangwa and the Metangula basins), with a marked regional unconformity at the Permian-Triassic transition.

In the Ruhuhu basin (Fig. 2), sedimentation continued during the Triassic, after a short interruption and a widespread unconformity at the Permo-Triassic transition (WOPFNER & KAAYA, 1992). At the junction between the Zambezi and Luangwa rifts in Zambia (Fig. 1), Early Triassic to Late Cretaceous extensional tectonics are recognised (OESTERLEN & BLENKINSHOP, 1994). The Metangula basin of North Mozambique (Fig. 2) evolved into a typical extensional graben after the Permo-Triassic transition, probably until Early Jurassic times (VERNIERS *et al.*, 1989). In coastal Tanzania, sedimentation continued during the Triassic with Karoo rifting activity and ended in the Early Jurassic (e.g. KAGYA, 1996).

This NE-trending basin system formed an integral part of the East Africa - Malagasy Karoo rift system. It extended up to the present East African coast and used to reach the Neo-Tethys margin of the Gondwana continent (Fig. 5). A short-lived uppermost Permian marine incursion in the Mikumi Basin of East Tanzania (KREUSER, 1983, 1984) suggests that this rift system was connected to the Tethys Sea margin of Gondwana, forming the "Malagasy Gulf" (WOPFNER & KAAYA, 1991; WOPFNER, 1994; VISSER & PRAEKELT, 1996). This is further confirmed by the presence of Late Triassic - Early Jurassic evaporites in the Manadawa hole, in southern coastal Tanzania (KAGYA, 1996).

3.2. NW-trending Late Carboniferous-Permian basins along the Ubende belt

A series of Karoo basins developed along the NW-trending Ubende belt. They contain Late Carboniferous to Late Permian sediments, but they lack Triassic sediments (MCKINLEY, 1965; DYPVIK *et al.*, 1990). In the TRM transfer zone in Tanzania, it was suggested that Karoo sedimentation was controlled by transpressional reactivation of the Ubende fabric (MBEDE, 1993; THEUNISSEN *et al.*, 1996; KLERKX *et al.*, 1998). West of Lake Tanganyika this trend continues by the Lukuga (Kalemie) basin, where Late Carboniferous to Permian sediments are present (FOURMARIER, 1914; LEPERSONNE *et al.*, 1977; CAHEN & LEPERSONNE, 1978). From the interpretation of multichannel seismic profiles in lake Tanganyika, SANDER & ROSENDAHL (1989) suspected the presence of Karoo sediments at the base of the sedimentary succession in the southern half of the basin. In the Rukwa depression, geophysical exploration and drilling for oil exploration by AMOCO demonstrated the presence of up to 3.5 km of Karoo sediments (WESCOTT *et al.*, 1991; MORLEY *et al.*, 1992). Karoo series are also outcropping in several places in the accommodation zone between the Rukwa and Malawi rift basins (Fig. 3).

Deposition of Karoo sediments apparently ended in the Late Permian in the TRM segment, east of Lake Tanganyika (MCKINLAY, 1965; DYPVIK *et al.*, 1990). Little is known about the structure of the Karoo deposits between Lakes Tanganyika and Malawi, due to sparse exposure and poor outcropping conditions.

3.2.1. Kalemie - Lukuga and Congo basins

Along the Congo side of Lake Tanganyika (Fig. 4), Karoo sediments of the Lukuga Group have been described in the Lukuga depression (Lukuga region near Kalemie). The Lukuga Group has been attributed paleontologically to the Upper Carboniferous-Permian (CAHEN & LEPERSONNE, 1978). It has been divided into a Lower sub-group and an Upper sub-group. The Lower sub-group contains glacial and periglacial sediments: tillites, calcareous sandstones, varval clays, and black shales. The Upper sub-group contains first the Lukuga black schist Formation, followed by the coal-bearing beds Formation. Deposition of the Lukuga Group ended in the late Upper Permian by the so-called Formation de transition, composed of brick-red sandstones and shales, conglomerates, and nodular limestones. This formation is transgressive over the lower, coal-bearing beds and lies on different layers of the Lukuga Group. This suggests the presence of a local unconformity, which might be of tectonic origin.

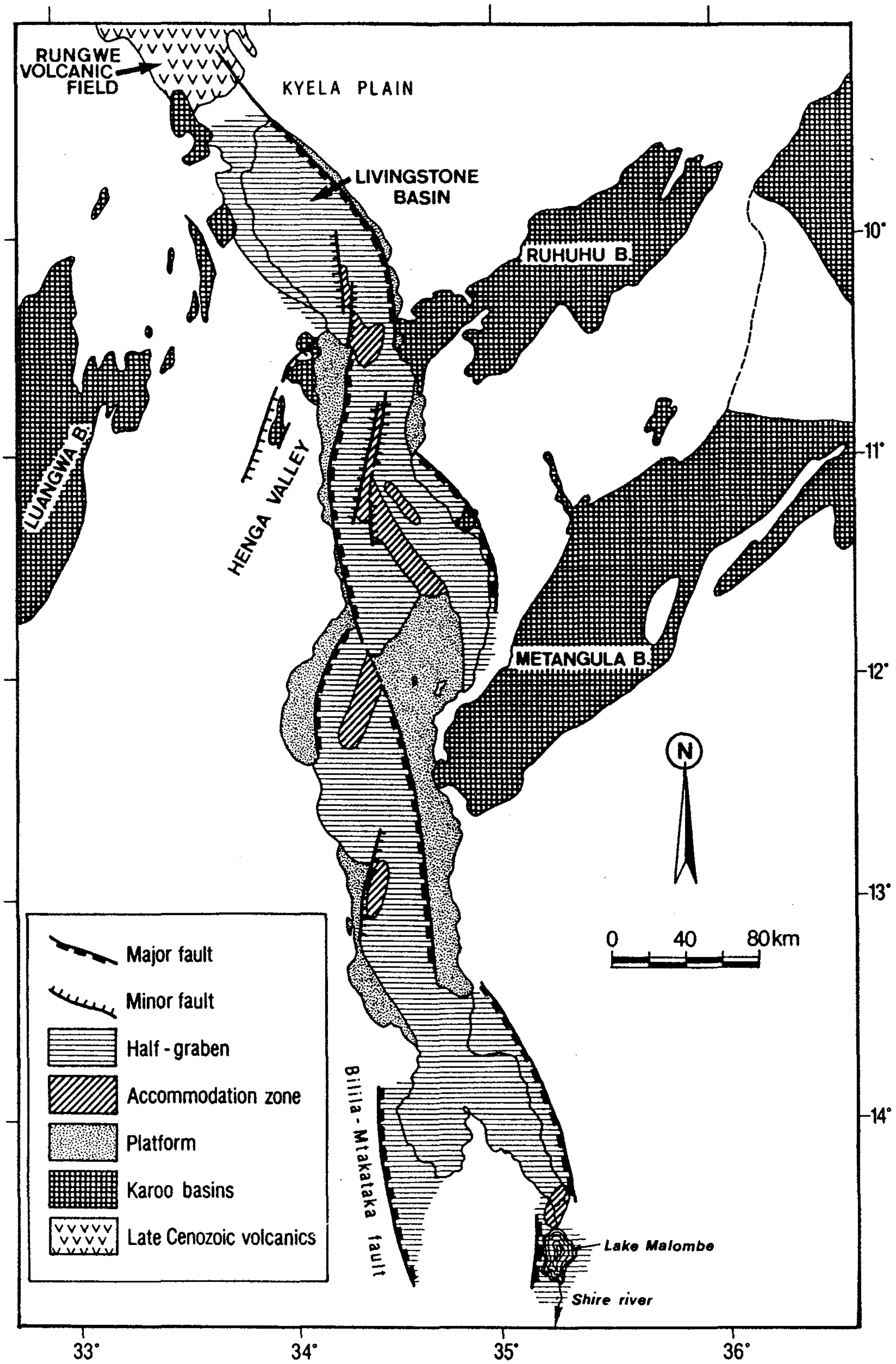

Fig. 2: General structure of the Malawi rift, based on SPECHT & ROSENDAHL (1989), compiled by DELVAUX (1991).

Important deformation of the Permian sediments occurred at the transition from the Permian to the Triassic (CAHEN & LEPERSONNE, 1978). In the Lukuga depression, FOURMARIER (1914) showed that sedimentation was controlled by tectonic activity and that the deformations were intensified at the end of the deposition of the Lukuga (Permian) series. He mentioned also that the Lukuga Karoo basin is affected by a major system of NNW-trending subvertical faults, dissecting the basin into a series of tilted blocks. He named these faults as "radial", by analogy to subvertical faults with horizontal displacement that affect the Westphalian coal basins of Belgium. Additional synthesis of observations from mining operations and drilling (CAHEN *et al.*, 1960; CAHEN & LEPERSONNE, 1971) indicate that important tectonic deformations of the Lukuga Group occurred certainly before the Lower Cretaceous, probably even before the Lower Triassic.

Seismic reflection profiles in the Congo basin (Cuvette Centrale, Fig. 5) evidenced that major compressional deformation affected the central part of the continent during the Late Permian - Early Triassic (DALY *et al.*, 1991). The stratigraphic interpretation of the seismic profiles is constrained by well and outcrop data. The sparse seismic grid shows the presence of a WNW-trending basement high, flanked by deep sedimentary basins, and bounded to the northeast and southwest by opposed divergent thrust systems. They correlated this event to extensional and strike-slip deformations associated to rift basin formation in other regions of central and east Africa. They further concluded that this intracontinental deformation seems to be the consequence of distant collisional process at the southern (in present coordinates) margin of Gondwana.

3.2.2. Rukwa - North Malawi basins in western Tanzania

The original extention and thickness of the Karoo deposits along the Ubende belt cannot be precisely reconstructed, but estimations can be made of the maximum overburden of Lower Karoo sediments and the thickness removed by post Karoo erosion. Field observation of the different Karoo basins along the TRM zone in Tanzania (MCKINLAY, 1965) indicates that the area of deposition of the Karoo sediments was originally much larger than the preserved distribution in isolated tectonic basins.

The stratigraphic succession of the Karoo sediments in western Tanzanian has been described by MCKINLAY (1965) and DYPVIK *et al.* (1990). They show that tectonic movements had a dominant control in the alternations of coal, clastics partly calcareous, and lacustrine sediments. A summary of the accepted stratigraphy based on these two works is presented hereafter.

After the pre-Karoo glacial erosion in the Late Carboniferous, glacial to periglacial sedimentation formed the K1 unit (tillites, varved clays, fine sandstones). The K2 unit forms the coal measures with alternating claystones, siltstones, sandstones, and coals (Upper Carboniferous - Lower Permian) in a lacustrine to fluviodeltaic and fluvial environment. A slight unconformity between the K1 and K2 units in the Galula coalfield (Fig. 3) and synsedimentary faulting during the deposition of K2 sediments are described by SPENCE (1954). The next unit (K3) is composed of red sandstones and shales, deposited in a fluviatile to fluviodeltaic floodplain. On top of this unit, calcareous beds reflect more lacustrine conditions, arid to evaporitic. The K4 unit, known in eastern Tanzania, is apparently absent in the Rukwa-North Malawi region. Of possible Upper Permian ages the K5 fine-grained green to grey silty marls and siltstones deposited in freshwater conditions are observed only in the Songwe-Kiwira coalfield, north of Lake Malawi (Fig. 3).

Samples of lower Karoo coal-bearing beds from the Ruhuhu basin in South Tanzania (Fig. 2) have been analyzed by KREUSER *et al.* (1988) for qualifying the maturity of organic matter. They obtained Tmax values ranging between 430 and 440°C, vitrinite reflectance index Rc between 0.75 and 0.82%, and a proportion of volatile matter between 22 and 25%. This places the maturity of all samples into the "oil window" and implies a significant overburden. Assuming a paleogeothermal gradient of 25-30°C/km, an estimated 2-3000 m of sediments must have overlain the coal-bearing Karoo beds in the Ruhuhu basin.

Further Rock-Eval analysis of coal samples from the K2 coal bearing layers by DYPVIK *et al.* (1990) indicates a maturity in the lower part of the oil window for the Songwe-Kiwira basin (Fig. 2) (Tmax: 430-450°C). Two samples from the Namwele coalfield (Fig. 4) have a lower degree of maturity (Tmax: 413 and 416°C), and a sample in the Muze basin (Fig. 4) gave a Tmax of 464°C, characteristic of a higher degree of maturity at the beginning of the gas window. The Namwele coal is highly volatile bituminous, containing 30-33% volatile matters, with a grade slightly inferior as for the Muze coal (MCKINLAY, 1965). According to MCCONNELL (1947), this coal formed from drifted

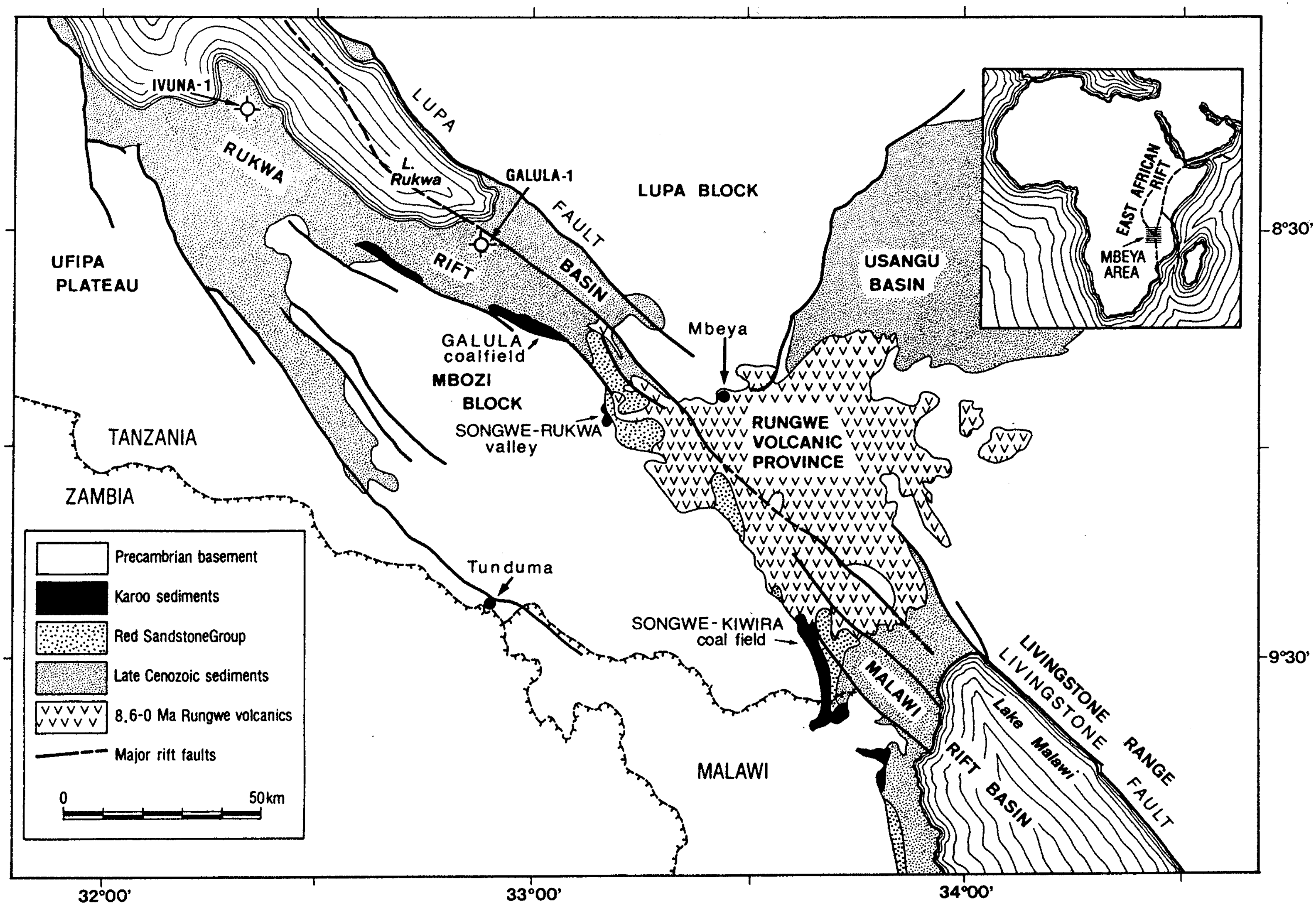

Fig. 3: Structure of the relay zone between Lakes Malawi (Nyasa) and Rukwa, with location of the Karoo outcrops and the Galula borehole (modified after DAMBLON *et al.*, 1998).

vegetation accumulating in shallow lake basins surrounded by flat land surface, rather than deep water far from land.

Apatite fission track thermochronology by VAN DER BEEK *et al.* (1998) on both flanks of the Rukwa and North-Malawi basins evidenced a regional denudation event at the end of the Karoo deposition, that removed a similar amount of 2 km of overburden over the entire region (Triassic-Jurassic). This corresponds to the widely recognised major erosional event, expressed partly in the "Gondwana surface" (WOPFNER, 1993).

Later denudation events occurred in the Late Jurassic-Cretaceous and in the Cenozoic, but the effects were more limited to the immediate vicinity of the present rift depression.

The two outcrops of red "doubtful Karoo" at the north-western end of the Rukwa depression are described lithologically by ISKHAKOV *et al.* (1970) as red sandstones, siltstones, lenses of conglomerates, grits, nodular limestones, and siliceous carbonate rocks. They tentatively attributed them to a "Cretaceous (?) System", without stratigraphic arguments. In the Namwele-Mkomolo coalfield, MCCONNELL (1947) described the Upper Sandstone Series as brick-red sandstones containing slay-shales and marls with calcareous nodules at the base. These form the upper part of the Karoo succession, also mentioned by MCKINLAY (1965) as possibly Cretaceous age. When compared, the description of the red "doubtful Karoo" of the Rukwa depression and the Upper Sandstone Series in the Namwele-Mkomolo coalfield appear lithologically similar. They are also comparable with the Formation de transition on top of the Permian Lukuga Group near Kalemie (CAHEN & LEPERSONNE, 1978).

The suggestion of a possible Cretaceous age of these red beds is based on a tentative correlation with the Red Sandstone Group in the South Rukwa - North Malawi area, itself correlated with the Dinosaur beds in Malawi. However, biostratigraphic analysis of the Galula borehole in the Rukwa depression (Fig. 3) by WESCOTT *et al.* (1991) and the determination of a fossil wood found in the Songwe-Kiwira area, north of Lake Malawi (DAMBLON *et al.*, 1998) have shown that this correlation is incorrect. The Red Sandstone Group appears now more likely as Eocene-early Miocene.

Tentatively it is considered here that the red "doubtful Karoo" at the northern end of the Rukwa depression and the Upper Sandstone Series of the Namwele-Mkomolo coalfield are more likely correlated with the Formation de transition of the Lukuga depression. The latter is attributed paleontologically and palynologically to the Upper Permian (CAHEN & LEPERSONNE, 1978).

The sparse knowledge reviewed above suggests that the Karoo formations along the TRM zone in Tanzania and the Lukuga-Kalemie zone in Congo are part of originally much larger sedimentary basins, filled by up to 2000 m of sediments and whose deposition was tectonically controlled. The maximum overburden at the Namwele-Mkomolo field might be less than 2000 m, and that on the Muze field might be more. Structural and facies relationships indicate that this series of basins was apparently trending NW-SE, parallel to the basement tectonic structures. It also appears that the fluvio-lacustrine sedimentation with coal deposition was interrupted by a major phase of tectonic activity at the end of the Permian. The red "doubtful Karoo", The Upper Sandstone series, and the Formation de transition are probably coeval with this event.

3.2.3. Inferred architecture of the Karoo deposits

The known distribution of Karoo deposits at the subsurface and their inferred presence at the bottom of the sedimentary succession of the Rukwa basin and the South-Tanganyika basin (Fig. 4) allow proposing the following tentative paleogeographic reconstruction.

During the Late Carboniferous-Permian period, Karoo sediments were apparently deposited in relatively shallow depressions, elongated along a NW trend parallel to the general basement fabric. The known and inferred occurrences of Karoo are aligned along two zones, which might represent two initial depression systems: the Kalemie - Lukuga - South Tanganyika (KLT) and Rukwa - Songwe - North Malawi (RSM) basins (Fig. 1). These probable zones of deposition are almost parallel to each other, arranged in an en-échelon, right-stepping system.

The Rukwa depotcenter was most probably extending up to the Namwele-Mkolomo coalfield, at the margin of the Ufipa block. The decreasing gradation of coal maturity from the Muze to the Namwele fields and the characteristics of deposition of the Namwele coals suggest that the Namwele-Mkolomo coalfield was located in a more marginal position than the Muze field. Structural interpretation of the seismic profiles of the Rukwa basin indicates that the deposition of Karoo sediments was intermittently controlled by fault activity (KILEMBE & ROSENDAHL, 1992). The same profiles also bear numerous indications of

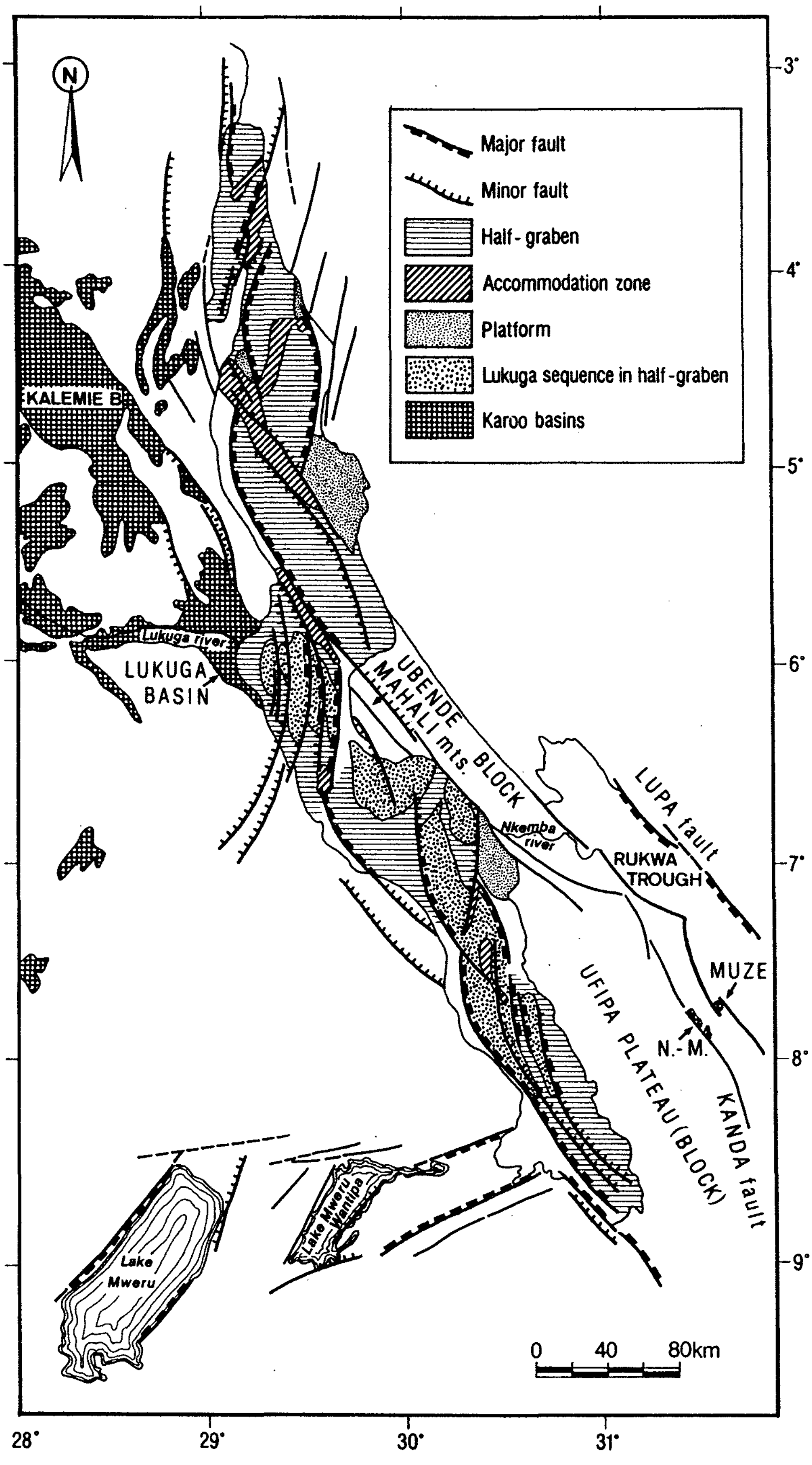

Fig. 4: General structure of the Tanganyika rift, based on SANDER & ROSENDAHL (1989), compiled by DELVAUX (1991). N.-M. = Namwele Mkomolo coalfield.

strike-slip faulting in a N-NW direction (flower structures, en-échelon and "zigzag" fault patterns). The travel time isopach maps for the Karoo in the Rukwa basin highlight the longitudinal trend of deposition and migration of depotcenters, parallel to the trend of the rift. The stratigraphic interpretation of the profiles evidence large lateral facies variations.

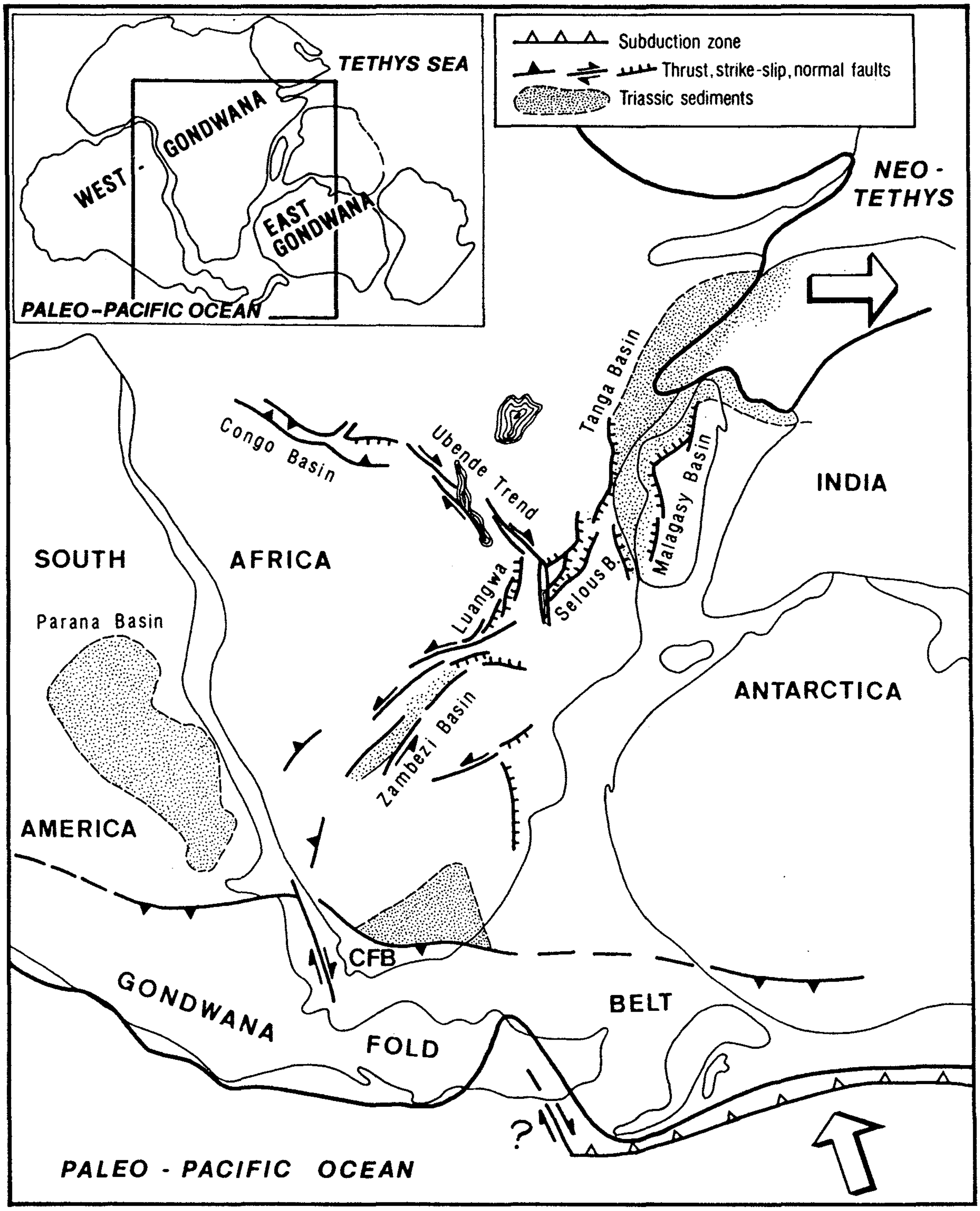

Fig. 5: Palaeotectonic map for the Permo-Triassic transition in the African sector of Gondwana. Compilation from DALY *et al.* (1991) and VISSER & PRAEKELT (1996). CFB: Cape fold belt in South Africa.

The structural high separating the inferred two Karoo depressions (Fig. 4) corresponds to the Ufipa block (to the SE) and the Ubende block (to the NW). No Karoo deposits have been found there, although McKINLAY (1965) has referred outcrops of sandstones and conglomerates near Karema to "doubtful Karoo", possibly basal Karoo or pre-Karoo. In places, these sediments are slightly metamorphic and sandstones were turned into quartzites. In later works (ISKHAKOV *et al.*, 1970) these sediments were considered as more likely pre-Karoo (late Neoproterozoic).

3.2.4. Late Karoo transpressional reactivation

Between the Rukwa and Tanganyika depressions, the Ubende belt has been affected by intensive brittle deformation. Examination of the DEM constructed from 1/50.000 topographic maps and Landsat-TM satellite images clearly evidence a network of narrow topographic depressions (lineaments), which highlight the fault systems and their associated crushed zones. As most of this fabric affects the Proterozoic basement, few indications are preserved to constrain the age of this fault system. First of all, it is reasonable to believe that this fault system evolved into several stages, one of them might be of late Karoo age and the most recent one, associated to the Late Cenozoic rifting.

Information on these basement faults is given in the detailed description of the Namwele-Mkomolo coalfield by McCONNELL (1947) and McKINLAY (1965). The coalfield is composed of several subbasins, tilting to the SW by 20° and limited on southwestern side by the so-called "Main Boundary Fault". Detailed field observations made by McCONNELL (1947) allowed him to suggest that this fault is subvertical and has a considerable horizontal component, greater than the vertical one. This fault is associated to a wide zone of tectonic breccia and crushed rocks. Also, red sandstones of the Upper Sandstone Series have been observed along it. These movements necessary post-date the deposition of the Lower Permian Karoo coal measures (K1-K2) and the undifferentiated Younger Karoo (? K3 - K4). They must also pre-date the formation of the Mid-Miocene African I peneplain capped by laterites.

The boundary fault of the Namwele-Mkomolo coalfield lies in the prolongation of the Kanda fault further south. This is presently a normal fault system with marked Holocene activity that reactivated an earlier dextral strike slip fault (VITTORI *et al.*, 1997; DELVAUX *et al.*, 1998). The normal slip on the Kanda fault dies out just north of the town of Sumbawanga. Crushed fragments of red sandstone have also been observed along it. Similar normal faults affect the Ufipa plateau more to the west (Mkunda and Mwimbi faults), probably also reactivating earlier fault systems.

Paleostress investigation in the coal series of the Namwele sub-basin and along the Kanda fault indicates that the strike slip movements occurred in a transpressional stress regime with N-S horizontal principal compression (DELVAUX *et al.*, 1998). Additional paleostress data were obtained and partly published in DELVAUX *et al.* (1998). They are from the northern extremity of the Mahali Mountains along the eastern coast of Lake Tanganyika (Fig. 4), from the Lupa fault on the north-eastern margin of the Rukwa basin, from the Mbeya-Tunduma area between the Rukwa and Malawi basins (Fig. 3), from the Livingstone fault zone along the northeastern margin of Lake Malawi, and from the Ruhuhu basin (Fig. 2). The obtained directions of compression range from NNE-SSW to NW-SE, with a strike-slip to transpressional stress regime.

More can be learned by integrating the structural interpretation of the DEM image and the satellite images with the detailed map of the Namwele-Mkolomo field produced by McCONNELL (1947). It appears that the lineaments observed at the vicinity of the coalfield lie in the continuation of the major faults with crushed zone and fault breccia mapped by McCONNELL. Therefore, it is reasonable to estimate that a significant part of the fault network that affect the basement in the Rukwa-Tanganyika transfer zone might have been (re)activated during the late to post-Karoo tectonic event.

Under this probable N-S compression, the NW-trending faults that controlled the deposition of the Karoo sediments in the Kalemie - Lukuga - South Tanganyika and Rukwa - Songwe - North Malawi basins were reactivated by dextral strike-slip. The movement was transferred from one basin system to the other trough the Karema transverse zone. This forms a WNW-trending tectonic boundary between the Ubende and Ufipa blocks, resulting from sinistral movements of Mesoproterozoic age, following THEUNISSEN (1988), but which might be also Neoproterozoic (THEUNISSEN *et al.*, 1996). During the late Karoo dextral transpression, this zone probably acted as a transpressional bridge between the two Karoo depressions. It should have concentrated deformation along the existing weak tectonic boundary.

4. Discussion and conclusion

The review presented above evidences a succession of three different tectonic stages during the Karoo period in the Ubende belt: Late Carboniferous-Permian rift-type evolution, Late Permian-Early Triassic transpressional inversion, and Triassic-Early Jurassic regional uplift and denudation with formation of the "Gondwana" morphological surface.

During the Late Carboniferous-Permian, the former glacial morphology is progressively eroded and a series of en-échelon basin systems developed in the NW-trending Ubende belt, orthogonal to the NE-trending Zambezi-Malagasy basin system. The basins along the Ubende belt were much larger than their present outcrop and were possibly assembled in two major basin systems: Kalemie - Lukuga - South Tanganyika (KLT) and Rukwa - Songwe - North Malawi (RSM). They were filled by Late Carboniferous - Permian fluvial-deltaic to lacustrine sediments and their subsidence was apparently tectonically controlled.

Deposition of the late Karoo red sandstones in the Lukuga basin (Formation de transition), in the Namwele-Mkomolo coalfield (Upper Sandstones Series), and at the northern extremity of the Rukwa basin was possibly coeval with the transpressional inversion in the Late Permian-Early Triassic. This tectonic pulse caused dextral transcurrent movements along the Ubende belt, reactivating its earlier fabric and deforming the Karoo sediments. Karoo sedimentation stopped at the end of the Permian but resumed after a regional unconformity in the NE-trending basins (Ruhuhu, Metangula, Selous...). This N-S intraplate compression can be related to the latest Permian - Early Triassic development of the Cape fold belt of South Africa (HÄLBICH *et al.*, 1983). This belt was part of the palaeo-Pacific active margin of Gondwana, associated with the palaeo-Pacific subduction beneath Gondwana during the Late Carboniferous to mid-Triassic times (ZIEGLER, 1993; VISSER & PRAEKELT, 1996). The observed intraplate compressional inversion in parts of East and Central Africa indicates a strong coupling between the orogen and the foreland during the Permo-Triassic transition, allowing the transfer of compressional stresses in the foreland. This occurred probably in a similar way as the intra-plate compressional deformation related to the Alpine foreland of western Europe (ZIEGLER *et al.*, 1995).

For the Triassic - Early Jurassic period, apatite fission track thermochronology (VAN DER BEEK *et al.*, 1998) in both of the northern and southern shoulders of the present Rukwa and Malawi (Nyasa) rift basins evidenced regional uplift and denudation. A total amount of 2000 m of overburden was probably removed during this period, leading to the formation of the "Gondwana" morphological surface. In eastern Tanzania, this was paralleled by intensified rifting activity along the future zone of crustal failure between Western and Eastern Gondwana (FOSTER & GLEADOW, 1993).

The model proposed here for the Karoo period in the Ubende belt is more detailed than the earlier model proposed by KLERKX *et al.* (1998). In this model, the Karoo basins of the Rukwa-Tanganyika area are considered to be strike-slip basins controlled by the reactivation of the Ubende structures. Globally this seems still valid, but here is proposed that the tectonically controlled sedimentation in subsiding basins and the strike-slip deformation at the basin margins are two subsequent tectonic stages rather than being two coeval processes in a transtensional setting. In this model, the Karoo basins are supposed to have formed in response to Late Carboniferous-Permian extension and subsequently deformed by Late- to post-Permian right-lateral wrench faulting.

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