Mus. roy. Afr. centr., Tervuren (Belg.), Dépt. Géol. Min.,
Rapp. ann. 1991-1992, 83-86 (1993).

EVALUATION OF NATURAL HAZARDS IN THE NORTHERN PART OF THE MALAWI RIFT (TANZANIA)

C. Ebinger [1], J. Klerkx [2], D. Delvaux [2] and A. Wüest [3]

[1] *Department of Earth Sciences, University of Leeds, Leeds, United Kingdom*
[2] *Musée royal de l'Afrique centrale, Département de Géologie et de Minéralogie, 3080 Tervuren, Belgique*
[3] *EAWAG, Swiss Federal Institute of Technology, Dübendorf, Switzerland*

Abstract. - The natural hazards in the northern part of the Malawi rift are evaluated. In this area all types of risks related to a rift zone are present. The seismic activity is intense and concentrates along the major NW-trending fault zones which extend into the lake. Numerous explosive volcanic eruptions occurred in the region during Pleistocene time; the Kiejo volcano, which still vents CO_2 from fissures, erupted in the late 1800's. The whole area is shown to experience regional tectonic tilting due to subsidence along the Livingstone fault bounding the eastern side of the lake. Furthermore, extensive accumulation of gas is present under a shallow cover of sediments over large areas in the northern part of the lake. Gas erupts in the lake along a NNW trending active fault : it consists of a mixture of CO_2 and CH_4.

Résumé. - Une évaluation est faite des risques naturels dans la partie nord du rift du Malawi. Tous les types de risques liés à une zone de rift sont présents dans cette région. Une intense activité sismique se concentre le long des failles majeures dirigées NW s'étendant dans le lac. De nombreuses éruptions volcaniques explosives ont affecté la région durant le Pléistocène, tandis que le volcan Kiejo a connu sa dernière éruption au siècle dernier et continue à émettre du CO_2 le long de fissures. La région entière est soumise à un basculement tectonique dû à la subsidence le long de la faille bordière de Livingstone, qui limite la partie orientale du lac. En outre, d'importantes accumulations de gaz sont présentes sous une faible couverture de sédiments sur de grandes étendues dans la partie nord du lac. Des gaz font éruption le long d'une faille active dirigée NNW au fond au lac; il s'agit d'un mélange de CO_2 et de CH_4.

Samenvatting. - De natuurlijke risico's in het noordelijk deel van de Malawi rift worden opgesomd. In dit gebied komen alle soorten risico's voor die aan een riftzone kunnen gebonden zijn. Een intense seismische aktiviteit is gebonden aan NW-gerichte hoofdbreuken die verder lopen in het meer. Talrijke explosieve vulkanische uitbarstingen hebben zich in de streek voorgedaan gedurende het Pleistoceen, terwijl een laatste uitbarsting van de Kiejo vulkaan gekend is uit de vorige eeuw; nog steeds wordt CO_2 uitgezonden langs breuken. Het ganse gebied ondergaat een regionale tektonische kanteling onder invloed van subsidentie langs de Livingstone breuk die de oostelijke kant van het meer afbakent. Bovendien wordt gas opgehoopt onder een dunne bedekking van sedimenten over een uitgestrekt gebied in het noorden van het meer. Gas wordt uitgezonden in het meer langs een NNW gerichte aktieve breuk; het is samengesteld uit een mengsel van CO_2 en CH_4.

INTRODUCTION

Rift zones are among the most active zones of the continental earth's crust : they are at risk to seismic, tectonic and volcanic hazards. The East African Rift System transects 14 countries, with associated uplift, faulting and volcanism affecting roughly one-fifth of the African continent. Although a large number of academic and a few commercial studies have been undertaken on the East African rift, risks within most of this huge area are virtually unknown.

The area north of Lake Malawi (Nyasa) is a region where all types of risks related to a rift zone are present: the area has been volcanically active during the last century, the region is seismically active, and recent studies show that the earthquake epicentres are located along major faults crossing the region; satellite interpretations and seismic reflection data show that both the lake and shore environment are dynamic and fragile, responding to active tectonics in the region; the methane-charged bottom waters of the anoxic Lake Nyasa bounded by active faults pose an additional risk, as at Lake Nyos (Cameroon).

GEOLOGICAL SITUATION

Lake Malawi (Nyasa) is the southernmost of the great East African rift lake partially filling the rift

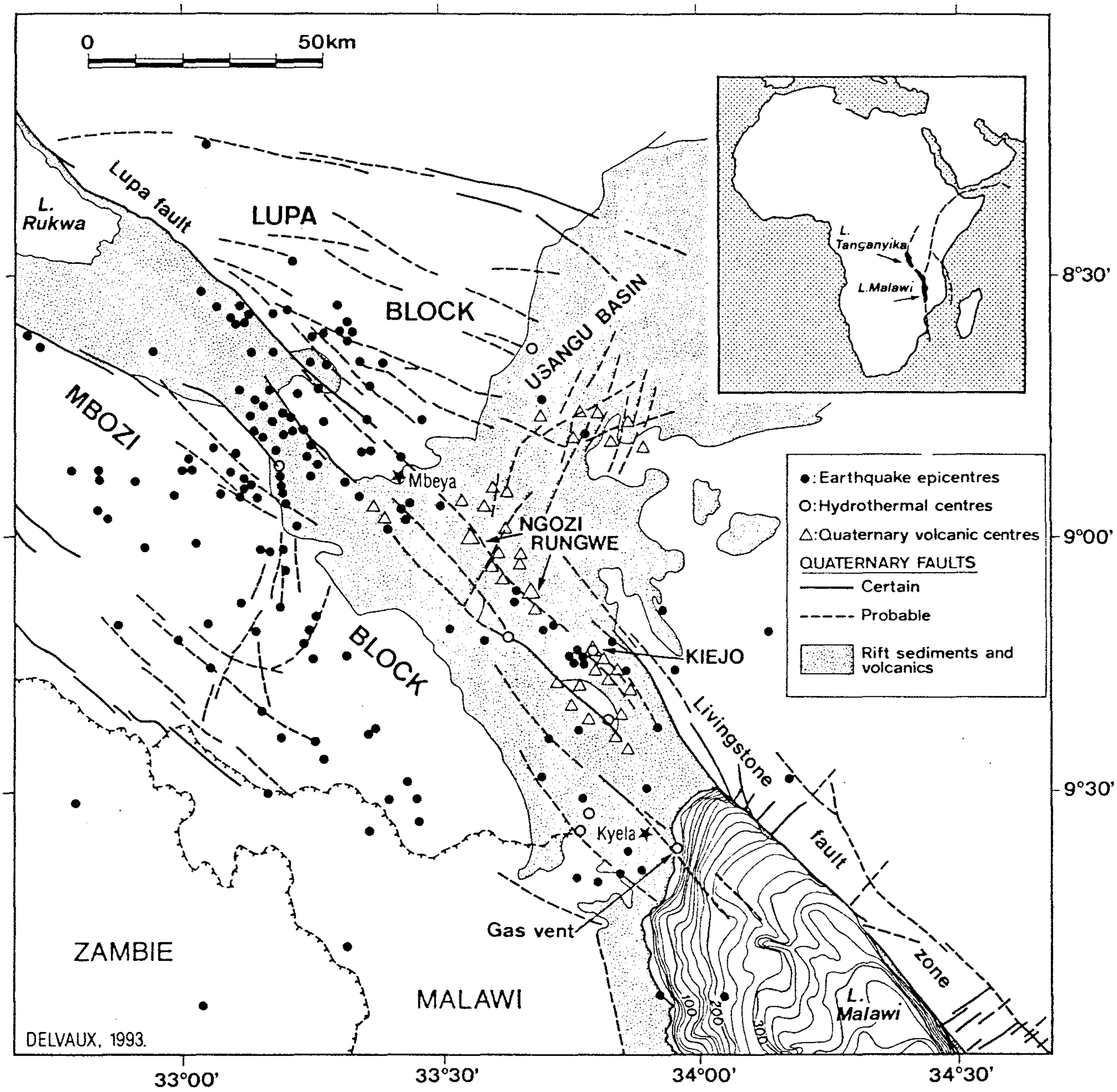

Fig. 1. - Distribution of active geological phenomena north of Lake Malawi (Nyasa) : active faults, Quaternary volcanoes, earthquake epicentres, hot springs and gas vents (modified from Delvaux and Hanon, 1993).

valley topography. The Tukuyu-Karonga basin lies at its northernmost end. Here, the rift valley is bounded by a steep fault escarpment (Livingstone escarpment) on its northeastern margin. A number of NW trending active faults, parallel to the Livingstone fault dissect the Tukuyu-Karonga basin and extends beneath the lake (fig. 1).

The active Rungwe volcanic province effectively blocks the Nyasa-Rukwa rift valley south of the town of Mbeya. At least two of the major volcanoes (Rungwe, Kiejo) have been active during the last 1 Ma, and a number of smaller cinder cones located along the Mbaka major fault were constructed during the last 0.5 Ma (Ebinger *et al.*, 1989).

Interpretation of negative Bouguer gravity anomalies suggest that magma may lie at shallow crustal levels beneath Rungwe volcano and Holocene eruptive centres a few kilometres south of the city of Mbeya (Pierce *et al.*, 1988; Ebinger *et al.*, 1989).

THE SEISMIC HAZARD

Historical records reveal that several earthquakes of magnitude greater than 6 have occurred within this area during the last century (Ambraseys and Adams, 1991). A recently installed local seismic network in the Mbeya region has recorded during five months of operation more than 1000 local and regional earthquakes with magnitudes ranging from 1.0 to 5.2 (Camelbeeck and Iranga, 1993, in press). These data indicate that the seismic activity concentrates along the major NW-trending fault zones at the northern end of Lake Nyasa : high seismic activity is recorded along the Livingstone fault, the Lupa fault and the Songwe fault (fig. 1). Considerable activity is also shown along the trend of the major volcanic centres (Rungwe and Kiejo).

THE VOLCANIC HAZARD

Numerous explosive eruptions occurred in the region during Pleistocene time. The morphology of volcanoes suggests that Rungwe has been active during the last 500 years, and the Kiejo volcano erupted in the late 1800's. This volcano still vents CO_2 from fissures. Explosive eruptions at Rungwe volcano at 11,000 BP blanketed areas within a 300 km radius with ash that is locally more than a metre in thickness (Ebinger *et al.*, 1989). The Quaternary geological record along the fertile lake plain contains evidence for widespread and potentially fatal ignimbrite flows, and deadly nuées ardentes (e.g. Harkin, 1960; Ebinger *et al.*, 1989; Tesha *et al.*, 1992). Deforestation of the upper slopes of volcanoes and farming along steep slopes increase the risk of landslides triggered by earthquakes or volcanic activity.

Hydrothermal activity is widespread in the region. The hydrothermal vents appear to coincide with major active faults. Gas release in the northern part of the lake has been recently observed. It shows to be located along the prolongation within the lake of one of the active faults on land which continues into the lake.

THE TECTONIC HAZARD

Four NW-SE flowing rivers (Songwe, Kiwira, Mbaka, Lufirio) drain the uplifted Rungwe volcanic province and carry sediments into the northern end of Lake Nyasa. Landsat imagery of the flood plains at the northern end of Lake Nyasa reveals that the Songwe, Kiwira, Mbaka and Lufirio rivers experienced an eastward shift in course during Quaternary-Holocene time. For example, the avulsion of the Mbaka river has led to the infilling of the estuary around Itungi Port, a major artery for goods transported from southern and central Africa via Lake Nyasa. The consistent change in direction of all four rivers points to regional tectonic tilting due to subsidence along the Livingstone fault bounding the eastern side of the lake.

High resolution seismic reflection profiling along off-shore regions also shows an eastwards migration of deltaic systems (Versteeg *et al.*, 1933).

During Quaternary time, fairly fluid phonolite and basalt flows from Rungwe volcano have followed the upper courses of the Kiwira and Mbaka rivers, also affecting their course (Tesha *et al.*, 1992).

Many earlier studies have attributed these tectonic changes in river base levels or lake levels to climatic changes, and largely ignored the response of the environment to rifting process. Studies of the architecture of similar spoon-shaped sedimentary basins have demonstrated that river networks are quite sensitive indicators of changes in the rift environment, and respond rapidly to tilting caused by faulting and volcanic inflation (e.g. Alexander and Leeder, 1987; Tilling, 1989; Reid, 1992).

THE GAS HAZARD IN THE NORTHERN PART OF LAKE NYASA

The gases which erupt at shallow depth in the northern part of the lake consist of a mixture of CO_2 and CH_4. The relative concentration of both gases indicates that their origin cannot be related to biogenic processes only, but that at least part of the gases originates at depth (Kipfer, per. comm.).

Morphological investigation of the lake floor and high resolution seismic profiling reveal a bottom morphology which can be related to gas eruptions up to depths of 300 metres, aligned along a NNW trending active fault zone.

Moreover, the seismic profiling reveals the presence of gas accumulation under a small cover of sediments (a few metres) over large areas in the northern part of the lake. The thick (more than 5 km), relatively unconsolidated sedimentary sequences at the northern end of the lake would amplify ground motions from a large earthquake, perhaps triggering landslides into the lake and or internal (seiche) waves. Either of these two could overturn the lake, releasing poisonous gases and causing the upwelling of the methane-charged bottom water of the anoxic lake.

Particularly the input of gases (CH_4 and / or CO_2) of deep origin may result in an oversaturation of gases in the sediments or in the deeper waters. These gases as a result of an earthquake, could reach the surface or affect the upper part of the water column, destroying all biogenic activity.

THE STABILITY OF THE WATER COLUMN

The vertical density structure of Lake Nyasa is characterized by small temperature gradients but a large thermal expansivity due to the high temperature. These compensatory effects lead to a density stability in the hypolimnion, which is not a typical also for temperate lakes.

As a consequence of the high temperature, the surface layer is subject to more intense convective mixing and is therefore usually deeper than the epilimnion of temperature lakes. Due to the great depth and the wind forcing, the upper thermocline (metalimnion) reaches also deeper than in most lakes on earth.

In the deep water of Lake Nyasa, the temperature gradient is nearly adiabatic and consequently the thermal stability is minor. The biogenically stimulated chemical gradient contributes to the density stratification in the hypolimnion and is solely responsible for the density stratification in the deepest 100 m. In addition, during the dry season, the dissolved solids play an important role for the meromixis of this lake.

REFERENCES

Alexander, J. and Leeder, M.R. (1987) - Active tectonic control on alluvial architecture. - *In :* Recent developments in fluvial sedimentology. Etheridge, F.G. and Harvey, M.D. (Eds.). - SEPM Spec. Publ., **39**, 243-252.

Ambraseys, N. and Adams, R. (1991) - Reappraisal of major African earthquakes south of 20°N, 1900-1930. - *Natural Hazards,* **4**, 389-419.

Camelbeeck, T. and Iranga, (1993) - Focal depth of earthquakes and geometry of active faults along the Rukwa trough, East Africa. - *Terra Abstracts, in Terra Nova,* 5, 1, p. 159.

Delvaux, D. and Hanon, M. (1993) - Neotectonics of the Mbeya area, SW Tanzania. - *Mus. roy. Afr. centr. Tervuren (Belg.), Dépt. Géol. Min., Rapp. ann. 1991-1992* (this volume).

Ebinger, D., Deino, A., Drake, R. and Tesha, A. (1989) -Chronology of volcanism and rift basin propagation, Rungwe province, East Africa. - *J. Geophys. Res.,* **94**, 15, 785-15, 803.

Harkin, D. (1960) - The Rungwe volcanics at the northern end of Lake Nyasa. - *Geol. Surv. Tanganyika, Mem. II,* 172 p.

Pierce, J. and Kipkov, L. (1988) - Structural interpretation of the Rukwa rift, Tanzania. - *Geophysics,* **53**, 824-836.

Reid, J.B. (1992) - The Owens River as a tiltmeter for Long Valley Caldera, California. - *J. Geol.,* **100**, 353-363.

Tesha, A.L., Ebinger, C.J. and Nyamwera, C.W. (1992) -Rift related volcanic hazards in Tanzania and their mitigation. - *In :* Seismology and related sciences in Africa. C.J. Ebinger, H.K. Gupta and I.O Nyambok (Eds.). - Tectonophysics, **209**.

Tilling, R.I. (Ed.) (1989) - Volcanic hazards. - *Amer. Geophys. Union,* **1**, 173 p.

Versteeg, W., Van Heuverswijn, M., Fernandez, M., Van Rensbergen, P., Back, R. and Klerkx, J. (1993) - Tectonics and sedimentation of the northern part of the Livingstone Basin, Lake Nyasa (Tanzania). - *Terra Abstracts, in Terra Nova,* **5**, 1. p. 736.