

SEDIMENTATION IN LARGE RIFT LAKES : EXAMPLE FROM THE MIDDLE PLEISTOCENE – MODERN DEPOSITS OF THE TANGANYIKA TROUGH, EAST AFRICAN RIFT SYSTEM

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TIERCELIN, J.-J., SOREGHAN, M., COHEN, A.S., LEZZAR, K.E. & BOUROULLEC, J.-L. (1992). – Sedimentation in Large Rift Lakes : Example from the Middle Pleistocene – Modern Deposits of the Tanganyika Trough, East African Rift System. – *Bull. Centres Rech. Explor.-Prod. Elf Aquitaine*, 16, 1, 83-111, 10 fig.; Bous-sens June 24, 1992. – ISSN : 0396-2687. CODEN : BCREDP.

La sédimentation récente dans le deuxième plus grand lac de rift du monde, le lac Tanganyika, Rift Est-africain, a été étudiée au cours du Projet GEORIFT de Elf Aquitaine (1983-1986). Cette étude repose essentiellement sur plusieurs centaines de kilomètres de sismique haute résolution (5 kHz), des carottages de type Kullenberg et des dragages. A la même période, le Projet PROBE (Duke University) a réalisé une sismique réflexion multitraces qui a permis l'identification de la structure profonde du fossé ainsi que de plusieurs séquences sismiques au sein de la série de remplissage. Parallèlement d'autres projets de recherche se sont développés, concernant en particulier la sédimentation carbonatée (University of Arizona) et l'hydrothermalisme (GROUPE TANGANYDRO).

Le lac Tanganyika est divisé en deux bassins, nord et sud, eux-mêmes constitués d'une mosaïque de sept sous-bassins fortement asymétriques, qui sont structurellement des demi-grabens séparés par des seuils transverses d'importance variable. Cette disposition tectonique résulte en plusieurs environnements morphologiques, escarpements de failles bordières, plate-formes littorales, seuils transverses, bassins axiaux profonds, qui influencent le réseau d'alimentation et l'hydrologie du lac, et par conséquence la sédimentation.

Les sédiments associés aux failles bordières sont des dépôts de piedmont, des glissements de terrain, cônes alluviaux, barres de bas de pente, et, plus localement, des sédiments hydrothermaux et minéralisations. Les plate-formes littorales sont essentiellement caractérisées par une sédimentation deltaïque, deltas latéraux ou axiaux reliés à des systèmes complexes de chenaux sous-lacustres empruntés par des courants de turbidité. Sur ces plate-formes se développe également une sédimentation carbonatée, sables oolitiques, lumachelles, stromatolites. Sédimentation gravitaire en bordure du littoral et sédimentation biogénique « offshore » sont typiques des abords des seuils transverses, qui contrôlent également le tracé de chenaux sous-lacustres.

Les bassins axiaux profonds sont essentiellement le lieu d'une sédimentation de type organique (maximum 12 % COT), favorisée par l'anoxicité des fonds lacustres. Ces dépôts s'avèrent être des roches mères potentielles, comme le prouve les indices d'hydrocarbures du Cap Kalamba. Les courants de fond qui se développent dans ces bassins contribuent à une sédimentation de type turbiditique et à la génération de rides migrantes.

Ces différents environnements sédimentaires sont discutés en termes de climat, tectonique et volcanisme. Les notions de roches mères et de réservoirs sont évoquées dans l'optique de l'exploration pétrolière de séries synrift.

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Mots-clés : Sédimentation lacustre, Sédimentation deltaïque, Quaternaire, Sédiments carbonatés, Sédimentation détritique, Contrôle tectonique, Afrique Est, Lac Tanganyika.

ABSTRACT

Recent and Modern sedimentation of the second largest rift lake in the world, Lake Tanganyika, East African Rift System, has been studied during the GEORIFT Project of Elf-Aquitaine (1983-1986). This study was mainly based on several hundreds of kilometres of high-resolution (5 kHz) seismic profiles, associated with multiple gravity coring and dredging. At the same time, the PROBE Project of Duke University collected multifold reflection seismic profiles, which have permitted the identification of several seismic discontinuities and sequences, as well as the deep tectonic structure of the trough. Onshore and offshore tectonic structures can now be related with the aid of field and satellite imagery observations. Other cooperative research programs were also developed, mainly concerning the carbonated sedimentation (University of Arizona) and the hydrothermal activity (TANGANYDRO GROUP).

The modern geomorphology of Lake Tanganyika is characterized by two main bathymetric basins, North and South, subdivided in a mosaic of seven strongly asymmetric sub-basins, which are all normally half-grabens. These sub-basins are separated by more or less developed and/or sediment-buried ridges of basement rocks. Such tectonic arrangement defines several morphological elements within the Tanganyika structure such as **border fault margins, littoral platforms, midlake structural highs and axial-deep basins**. Such present geomorphology strongly influences the drainage pattern as well as the hydrology of the lacustrine domain. Analyses of Recent-Modern sediments indicate that the sediment has two main origins, allochthonous and autochthonous. Particular facies geometries and occurrences can be related to the particular tectonic-geomorphic settings cited above.

Sedimentation associated with border fault margins includes piedmont deposits, colluvial rockfalls, fan deltas and downslope bars, and locally, at N-S/NW-SE crossing faults, hydrothermal sediments and mineralization. Sedimentation related to littoral platforms is characterized by fan deltas and deltas associated with lateral littoral platforms, as well as by prograding deltas associated with axial littoral platforms. High density underflows generated by cold, sediment-rich streams are characteristic of most Tanganyika deltas and are related to sublacustrine canyon and channel systems which deeply incise platforms and slopes. Peculiar carbonate deposits, ooids shoals, coquinas, stromatolites, are also associated with such littoral platforms. Sedimentologic processes along midlake structural highs are dominated by the interacting of gravity-driven sedimentation nearshore and biogenic sedimentation offshore. Deltas also develop, characterized by poorly sorted delta front sediments. Channel and canyon systems associated with such deltas are generally confined by the structural grain of the midlake highs.

Sedimentation related to axial-deep basins is mainly of autochthonous origin. Wide "sheet drape" sequences are formed by homogeneous or laminated organic-rich muds. A maximum TOC of 12% found in modern sediments of the Northern Tanganyika Basin is explained by anoxic conditions which are present over most of the bottom of the lake. Locally, such sediments have a high petroleum potential, possibly explaining the oil occurrence in the area of Cape Kalamba, Northern Tanganyika. Deep currents at the bottom of the lake result in distal turbiditic sedimentation and also generate sediment waves, resulting in alternating clastic and organic layers.

Such sediments and sedimentary bodies related to particular tectonic-geomorphic settings are discussed in terms of the influences of climate, tectonism and volcanism. Implications for hydrocarbon exploration in synrift series are analyzed, mainly in terms of source rocks and reservoirs.

Key-words : Lacustrine sedimentation, Deltaic sedimentation, Quaternary, Carbonate sediments, Detrital sedimentation, Structural controls, East Africa, Lake Tanganyika.

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INTRODUCTION

Bottom sediments of the largest lake of the East African Rift System, Lake Tanganyika (length 650 km; surface area 32600 km²; volume 18800 km³; maximum depth 1470 m) (COULTER, 1991) (Fig. 1), were first studied during the Belgian "Mission hydrobiologique au lac Tanganyika" (1946-1947) led by E. LELOUP (LELOUP, 1949). Sedimentary facies were identified using echosounding supplemented in places by sediment dredging. Sediment cores were successfully obtained from the lake bed in 1961 (LIVINGSTONE, 1965) and 1970 (DEGENS *et al.*, 1971).

Our present knowledge of Recent and Modern sedimentation in Lake Tanganyika is largely based on high-resolution (5 kHz) seismic surveys associated with multiple gravity coring and dredging, made during the GEORIFT Project of Elf-Aquitaine (1982-1985) which was supported by the European Economic Community (EEC) and the "Fonds de Soutien aux Hydrocarbures". Multifold seismic profiles collected during the PROBE Project (Duke University) have permitted the identification of several seismic discontinuities and associated sequences in the sedimentary pile, which were interpreted in terms of sedimentary processes and paleoenvironments (ROSENDAHL *et al.*, 1986; BURGESS *et al.*, 1988; SCHOLZ & ROSENDAHL, 1988). Other research programs were developed at about the same time along the lakeshores of Burundi, Tanzania and Zaire, mainly concerning

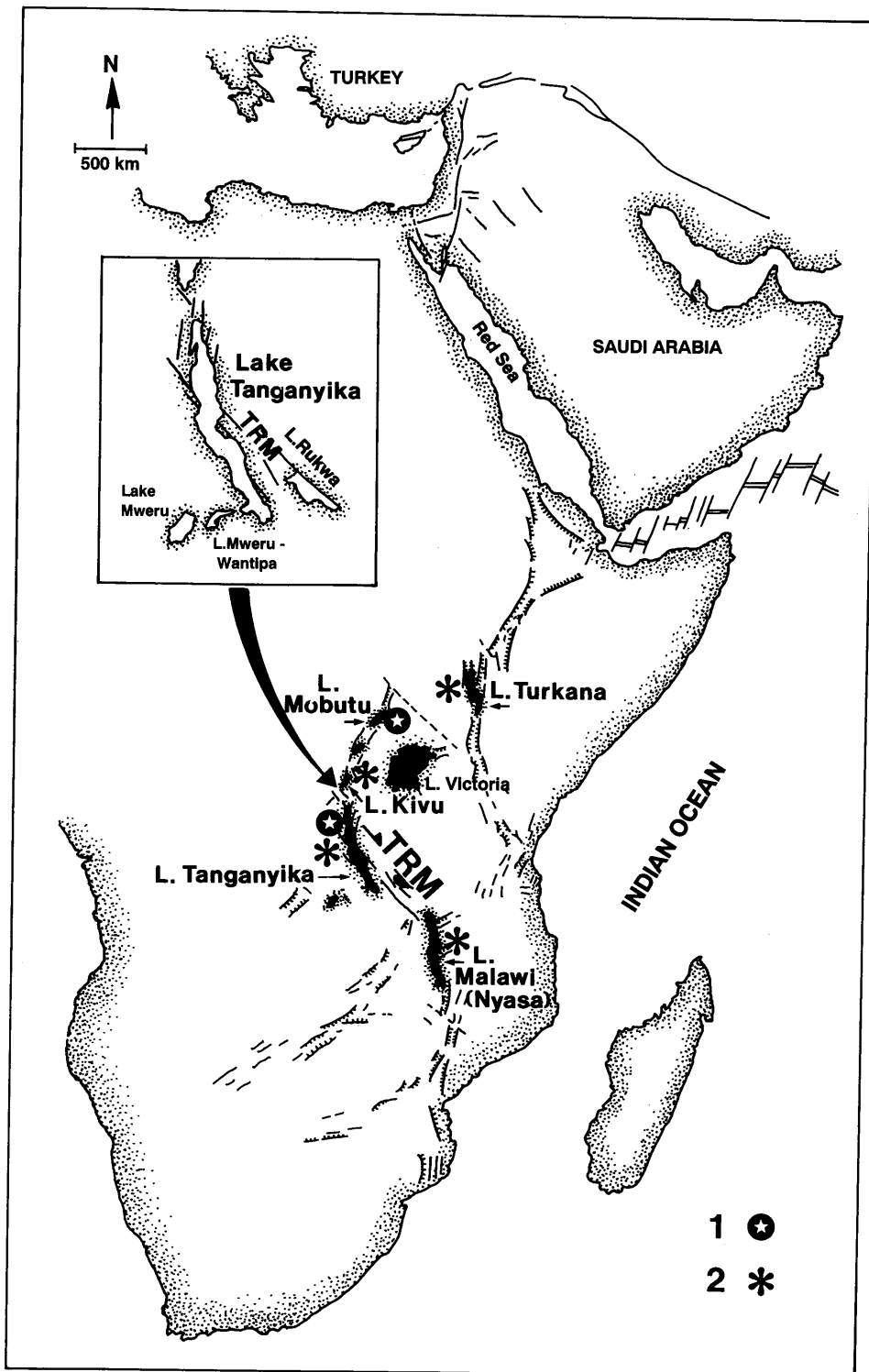


FIGURE 1

Lake Tanganyika, the second largest rift lake in the world, belongs to the western branch of the East African Rift System. Hydrocarbon occurrences within the EAR System : 1) Modern oil seeps; 2) Methane and other hydrocarbon gases.

surveys of littoral carbonate sedimentation (University of Arizona) (COHEN & THOUIN, 1987; CASANOVA & THOUIN, 1990) and sublacustrine hydrothermal activity (TANGANYDRO Project) (VASLET *et al.*, 1987; TIERCELIN *et al.*, 1989a; TANGANYDRO GROUP, 1992; TIERCELIN, BOULÈGUE & SIMONEIT, in press). Data presented here are a compilation of published or unpublished results acquired during these various research projects.

1. — THE MODERN GEOMORPHOLOGY OF THE TANGANYIKA TROUGH. ITS INFLUENCE ON DRAINAGE PATTERNS

The deep structure and stratigraphy of the Tanganyika Trough have been investigated by multifold reflection seismic studies (PROBE Project) (ROSENDAHL *et al.*, 1986; ROSENDAHL, 1987; BURGESS *et al.*, 1988). Structural field and satellite imagery observations have been used to relate onshore and offshore tectonic structures (CHOROWICZ *et al.*, 1987; TIERCELIN *et al.*, 1988a; ROLET *et al.*, 1991) (Fig. 2A). During its early history, Lake Tanganyika appears to have consisted of three

large depositional basins, the Ruzizi, Kigoma and Southern Basins, which were separated by the Ubwari and Kalemie-Mahali horst blocks respectively (BURGESS, 1985; BURGESS *et al.*, 1988) (Fig. 2B).

The modern geomorphology of Lake Tanganyika is characterized by two main bathymetric basins, that of the North (3° 20' to 5° 40' S) and that of the South (6° 50' to 9° S) (Fig. 2 C, D). In detail, the lake basin comprises a present-day mosaic of seven "en touches de piano", strongly asymmetric, rectangular-shaped sub-basins, mainly oriented NNE-SSW to NW-SE. From North to South, these are : the Bujumbura, Rumonge, Kigoma (Eastern and Western), Kalemie, Moba, East-Marungu and Mpulungu sub-basins (EBINGER, 1989; ROLET *et al.*, 1991; TIERCELIN & MONDEGUER, 1991) (Fig. 2C, D). These sub-basins are internally faulted and separated by more or less developed and/or sediment-buried ridges of basement rocks, which serve as barriers to sediment spillover. The two main ridges are respectively

— the Ubwari shoal, which forms the lakeward extension of the N20° Ubwari horst block and divides the Bujumbura and Rumonge sub-basins;

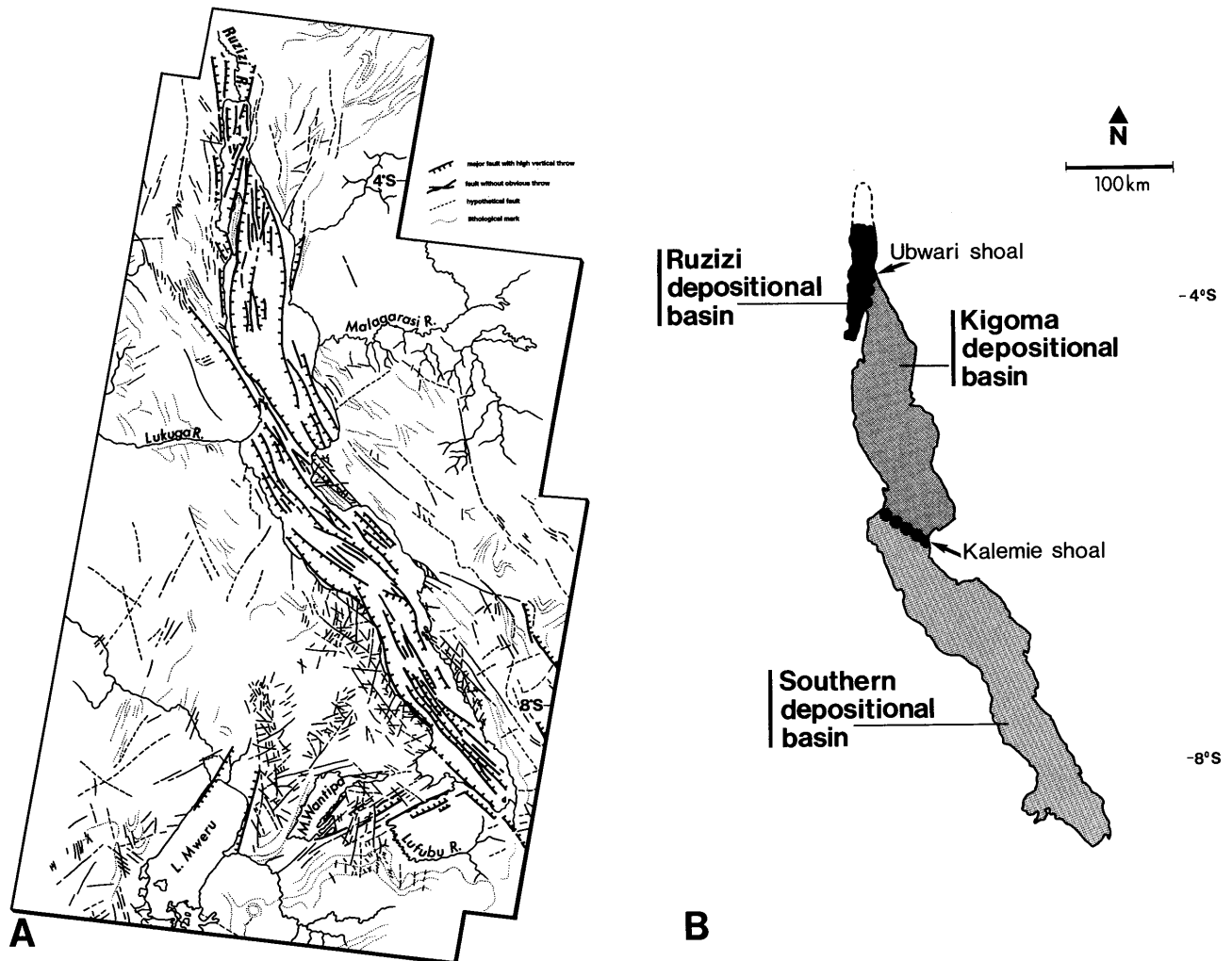


FIGURE 2

A : Fault map of the Tanganyika Trough deduced from MSS Landsat imagery and PROBE seismic profiles (from MORLEY, 1988; MONDEGUER, 1991); B : Early depositional basins of the Tanganyika Trough (from BURGESS, 1985);

— the Kalemie-Mahali shoal, a N130-140° complex block-faulted structure belonging to the Tanganyika-Rukwa-Malawi transcurrent Fault Zone (TRM FZ) (TIERCELIN *et al.*, 1988a) that divides the Kigoma and Kalemie sub-basins.

The deepest areas of Lake Tanganyika are located in the Kigoma sub-basin, with a maximum water depth of 1310 m at the "Baron Dhanis Deep", and in the East-Marungu sub-basin with a maximum depth of 1470 m at the "Alexandre Delcommune Deep" (Fig. 2 C).

These depositional basins are all normally half-grabens with one dominant system of normal faults bounding each half-graben. Where basin troughs widen (> 30-50 km), they may comprise half-graben to full graben geometry (MORLEY, 1988). The present throw of the boundary faults reaches as much as 8 km, which has allowed the deposition of more than 4 km of sediment in the deepest parts of these basins (ROSENDAHL *et al.*, 1986; BURGESS *et al.*, 1988). Such tectonic arrangement defines several morphological elements within the Tanganyika structure such as border fault margins, littoral

platforms, midlake structural highs and axial-deep basins (Fig. 3A).

The marked tectonic trends and asymmetry of the sub-basins strongly influence the drainage pattern along the rift margins. Among the four main permanent tributaries to Lake Tanganyika, the largest tributary to the basin is the Malagarasi River, flowing into the lake on the eastern shore after a 475 km long circuitous course in Western Tanzania, which has been interpreted as the result of a capture after a fall in the lake-level (SALÉE, 1927) (platform margin drainage of COHEN, 1990) (Fig. 3A, B). The Lugufu and Luegere Rivers (160 km and 95 km long respectively) are both backshed drainage reentrants (COHEN, 1990) which ultimately enter the lake along the Malagarasi Platform. The Lufuku and Lufubu Rivers (190 km and 290 km length respectively) are backshed drainage reentrants on the west side of Lake Tanganyika. The Lufubu River flows into the southern Mpu-lungu sub-basin via a fault-oriented downstream course controlled by the N70° Mweru-Mweru Wantipa fault zone, a conjugate structure to the TRM FZ (MONDEGUER *et al.*, 1989;

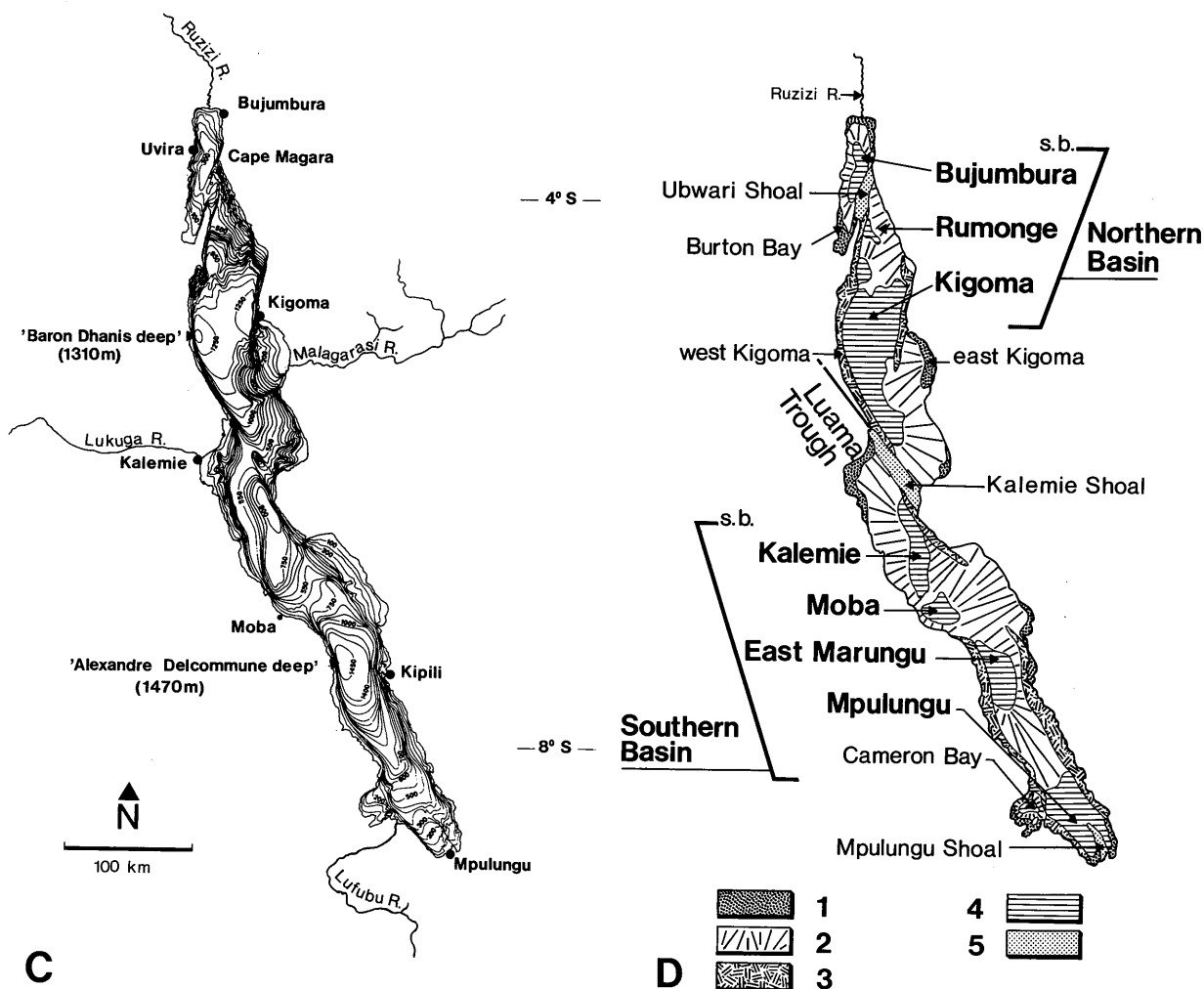


FIGURE 2 (continued)

C : The bathymetry of Lake Tanganyika. Bathymetric data are from CAPART (1949) and from Project GEORIFT; isobaths in metres; D : Present-day geomorphology of the Tanganyika Trough; 1) Littoral platforms; 2) Talus; 3) Escarpments (> 10°); 4) Sub-basin deep zones; 5) Transverse shoals; s.b. : sub-basin (from MONDEGUER, 1991; TIERCELIN & MONDEGUER, 1991).

