Tanzania Journal of Science 46(2): 383-396, 2020
ISSN 0856-1761, e-ISSN 2507-7961

Sedimentology and Paleocurrent Study of the Early Triassic Rocks in the Ruhuhu Basin, SW Tanzania

Audax Syprian Kiwango* and Diwakar Mishra
Department of Geology, College of Earth Sciences and Engineering, The University of Dodoma, P. O. Box 259, Dodoma, Tanzania
E-mail addresses: kiwangoaudax@gmail.com; mishradiwakar988@gmail.com
**Corresponding author*
Received 14 November 2019, Revised 9 April 2020, Accepted 27 April 2020, Published June 2020
DOI: https://dx.doi.org/10.4314/tjs.v46i2.16

Abstract

The sedimentary succession ranging in age from Permian to Early Triassic in Ruhuhu basin was subdivided into eight informal lithostratigraphic units, identified by the symbols from K1 to K8. Manda Formation (K8) belongs to Early Triassic age and comprises two Members, i.e., Lower Kingori Member and Upper Lifua Member (150-200 m thickness). The implications of present study relate to inter and intra basinal correlations which may provide regional depositional framework from a mass of local details. Present investigation connoting the lithofacies studies in conjunction with palaeocurrent and grain size analysis of the early Triassic strata aims at interpreting the depositional environment of Lifua Member. Based on the present study, five lithofacies have been identified, namely (i) Massive matrix supported paraconglomerate (Gmm), (ii) Massive sandstone (Sm), (iii) Parallel-horizontal laminated sandstone (Sh), (iv) Planar cross-bedded sandstone (Sp) and (v) Fine silt, mud and clay (Fl). Sandstone facies (Sm, Sh, and Sp) exhibit normal grading and unimodal palaeocurrent direction. Grain size analysis indicated that the sandstones were moderately sorted, finely skewed, mesokurtic and most of the grains were silty-sand. Bivariate scatter plots suggest that the Lifua Member sandstone is of riverine environment. Lithofacies, palaeocurrent and grain size studies suggest fluvial environment dominated by sand channel deposits.

Keywords: Lifua Member; Early Triassic; Lithofacies, Paleocurrent; Channel deposits; Ruhuhu basin

Introduction

The Ruhuhu Basin is located in the south west Tanzania and contains all lithostratigraphic units of Permo-Carboniferous to Early Triassic (Karoo succession). The NE-SW trending Ruhuhu Basin is one of the chain of Karoo basins across southern Africa that formed during the break up of Gondwana Supercontinent in the Late Carboniferous/Early Permian (Kreuser et al. 1990).

The sedimentary succession ranging in age from Permian to Early Triassic in Ruhuhu basin is subdivided into eight informal lithostratigraphic units, identified by the symbols from K1 to K8 (Wopfner et al. 1991). K8 is termed as Manda Beds that are of Early Triassic age and is the youngest stratigraphic unit of the Karoo sequence of the Ruhuhu basin. Charig (1957) raised the status of Manda Beds as the Manda Formation and composed of two Members, i.e., Lower Kingori Member and Upper Lifua Member. Ruhuhu basin exhibits excellent outcrops of all units, amounting to a cumulative total thickness of up to 3,000 m (Catuneanu 2005). The study has been conducted in the Lifua Member. Most of the

Lifua Member units are located in the western part of the Ruhuhu basin bordering Lake Nyasa. The study area lies between 34°36′E-34°48′ E and 10°27′S-10°30′S and covering an area of approximately 250 km^2.

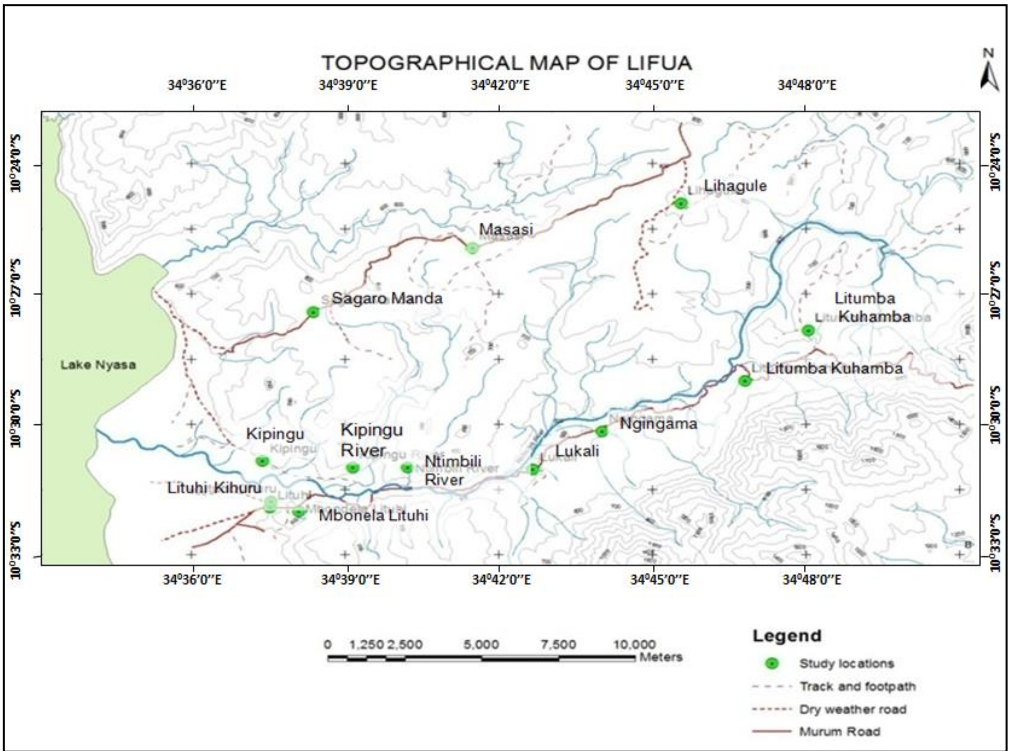
Through the proper study of sedimentary rock deposits, interpretation of geological history of the area is feasible. Sedimentary structures such as planar cross bedding and trough cross bedding are the most directional sedimentary structures that are applicable in paleocurrent measurements (Selley 2000). The measurement of paleocurrent indicators is important in the study of sedimentary rocks, since they provide information on the local/regional palaeoslope, depositional environment, current and wind directions which are useful in facies interpretation (Tucker 2003). Paleocurrent studies along with facies/subfacies analysis and grain size studies could provide a clear picture of depositional environment. Most of the studies conducted in the Ruhuhu Basin focused mainly on the paleontology and the economic potential of coal accumulations in the basin (Kreuser et al. 1990, Nesbitt et al. 2014, Barrett 2015). However, studies on the depositional environment have been given little attention to date. So taking the importance of depositional environment, the present investigation applies integrated approach of lithofacies studies in conjunction with palaeocurrent and grain size analysis of the Early Triassic strata in interpreting depositional environment of Lifua Member. Analysis of paleocurrent pattern needs to be combined with study of lithofacies and grain size for maximum information. In order to reconstruct depositional environment and paleogeography, it is essential to establish regional framework. In this context, the present study will be useful for inter and intra basinal correlations which may provide regional depositional framework from a mass of local details. It may also provide some alternative ideas for depositional modelling in fluvial domain. Topographic map of Lifua showing the location of the studied sections is shown in Figure 1.

Geological setting and stratigraphy

The Karoo basins of Tanzania occur mainly as grabens or half-grabens tilted to the direction E–SE or S. They are faulted into the Ubendian basement. Boundary faults post-date the deposition and were active most probably during middle Jurassic as a result of the breakup of Gondwana (Kreuser et al. 1990). Some of the basins that comprise Karoo rocks in Tanzania are Tanga basin, Ruvuma basin, Ruhuhu basin, Rufiji trough and Njuga basin.

Earlier studies of the Ruhuhu Basin date back in 1890's during which coal was discovered (Stockley and Oates 1937). Later on, extensive drilling programs started at various parts of Ruhuhu basin and other parts of Tanzania such as Ketewaka-Mchuchuma and Ngaka coalfields (Semkiwa 1992). The Ruhuhu Basin is not only the basin that still comprises a fairly complete succession of typical Karoo beds, but also due to its elevated position on the shoulder of the Neogene Nyasa Rift it provides excellent outcrop of all units, amounting to a cumulative total thickness in excess of 3,000 m (Catuneanu 2005).

The sedimentary succession ranging in age from Permian to Early Triassic in Ruhuhu basin is subdivided into eight informal lithostratigraphic units, identified by the symbols from K1 to K8 (Wopfner et al. 1991, Figure 2). K1 to K6 represent Permian succession and they are in ascending order in which K1 represents Glacigene deposits, K2 represents a lower coal bearing unit, K3 represents red and green arkoses, K4 represents an upper coal bearing unit, K5 represents lacustrine carbonates, and K6 represents multicolored siliciclastics with vertebrate remains (Kreuser et al. 1990). K7 and K8 are termed as Kingori Sandstone and Manda Beds, respectively. The beds are of early Triassic age and are the youngest stratigraphic units of the Karoo sequence of the Ruhuhu basin.



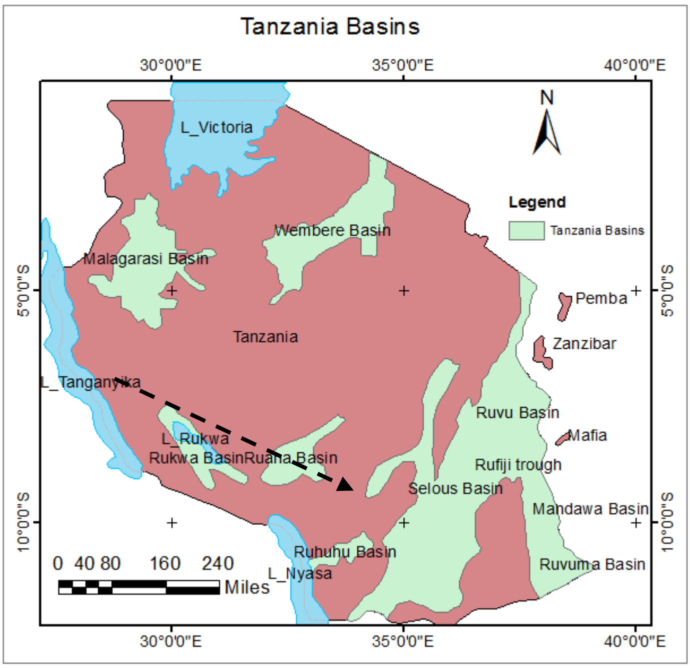


Figure 1: Topographic map of Lifua showing the locations of the studied sections (modified from Douglas Lake Minerals Inc. 2011).

In this aspect, it could be stated that Charig (1957) was the pioneer in raising the status of Manda Beds the youngest unit which was deciphered earlier by Stockley and Oates (1937). After this description, the Kingori Sandstones have become the Kingori Sandstone Member of the Manda Formation, and original Manda Beds has become a subunit of the formation called the Lifua Member. On the basis of comparison with the tetrapod fauna of subzone C of the *Cynognathus* Assemblage Zone of South Africa, the Lifua Member is considered to be Anisian in age (Nesbitt et al. 2014).

A shale pebble conglomerate, consisting of clasts derived from the underlying multicoloured and marls of the K6 unit marks the base of the Kingori Sandstone (Wopfner et al. 1991). This unconformity between K6 and K7 marks the boundary between the Permian and the Triassic as supported by the different vertebrate faunas contained in the Lower Bone Bed 'K6' and in the Manda Beds 'K8'.

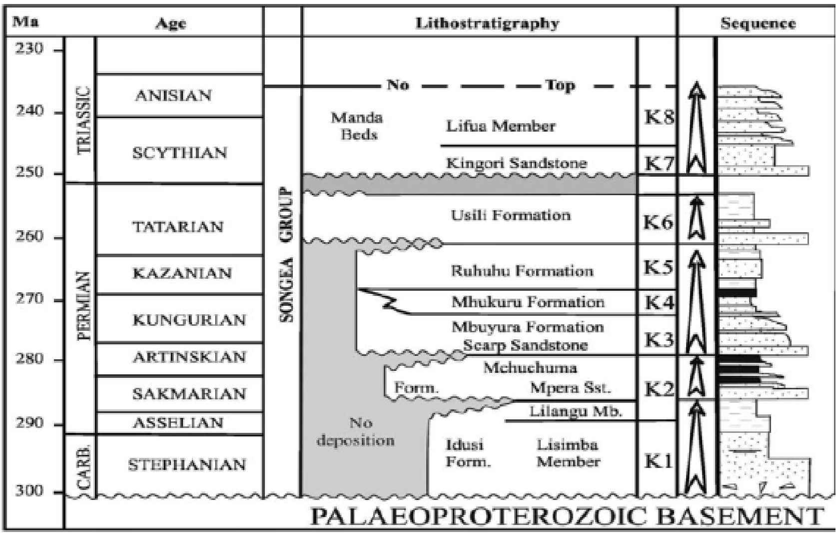


Figure 2: Stratigraphic table of the Songea Group as established in the Ruhuhu Basin (adopted from Catuneanu 2005).

Methodology

The fieldwork was conducted between February and March 2016 and involved identification of outcrops of the Lifua Member-Manda Beds especially on the flanks of rivers and on the sides of road cuts. Each outcrop was evaluated and interpreted in terms of lithology, sedimentary structures, texture, and palaeocurrent measurement together with collection of samples. Vertical profiles and other length related dimensions of beds were also measured.

Lithofacies and their classification

Each succession was recorded and examined in detail, thereafter the recorded sediments attributes were observed. The depositional structures were considered first since these reflect the depositional processes excellently; then followed by texture, lithology and fossil content. Everything was named or numbered for future reference. Once the various facies have been differentiated, a table with their various features (name, code, typical thickness or thickness range, grain-size, sedimentary structures, fossils and colour) were prepared. The code schemes used in text for denoting different facies are adopted from the classification-scheme of Miall (1978).

Paleocurrent measurement

Paleocurrent measurements were made by recording the azimuth (direction relative to the true north) of three dimensional planar cross beds using Silver-type compass clinometers. First, the outcrop was assessed. Outcrop that showed only one type of lithofacies, measurements were made from any or all of the beds. Few measurements were made from one bed (or many beds at an outcrop) which resulted into similar measurements because they are sufficient to give an accurate vector mean. Large numbers of measurements were collected on areas where readings varied greatly within a bed. Apart from measuring azimuth, dip amounts of the planes were also made in order to verify whether correction for tilt effect was to be done or not.

Grain size analysis

Sieving analysis was performed to determine the grain size distribution of the samples. Representative unconsolidated samples from each identified section were subjected to grain size analysis. Grain size analysis was done based on British Standards with a sieve set in the order of mesh sizes: 500, 355, 212, 106, 75 and 45 µm. About 200-350 g of the dry sample was sufficient for analysis. The sieves were arranged in a stack or nest with the coarsest sieve on the top and the finest at the bottom, and then the sample was placed thereafter tightly fitting pan or receiver below the finest sieve and a lid on top of the coarsest sieve to prevent sample losses. After about 20 minutes, the materials on every sieve were weighed and tabulated.

Results and Discussion

Lithofacies analysis

The majority of the Ruhuhu Rift-basin outcrop area belongs to pinkish gray feldspathic sandstones, medium dark gray sandstones and gritstones of the Triassic Manda Formation (Kingori-Lifua Members). The sandstones are medium to coarse-grained, grey to pink in colour, commonly cross bedded and parallel laminations. Most of the selected outcrops show repeated fining upwards sequence (Figure 3). Lithofacies and codes applied in this study are modified after Miall's classification schemes (Mial 1978, Mial 1996, Mtelela et al. 2016). The criteria principally applied concern grain sizes and sedimentary structures, the geometry of sedimentary bodies, and presence or absence of identifiable plant remains (fossils). Based on this scheme, about five lithofacies were identified as indicated in Table 1.

Paraconglomerates (Gmm)

These facies comprise massive conglomerate matrix supported with bed thickness ranging from 0.3 to 1.6 meters observed at Lituhi Kihuru. Clasts include pebbles, cobbles and boulders of various sizes ranging from 0.4 to 10 cm in diameters and float in matrix of very fine to very coarse sand. These clasts are angular to subrounded, poorly sorted and made up of mainly quartz. The long axes of the clasts are randomly arranged; however, some areas show imbrications with most of them orienting North-East, South-West (NE/SW). These facies are poorly consolidated and are made up of dark yellowish brown rocks. It shows normal grading, that is, clasts are fining upward (Plate 1).

Interpretation: The absence of sedimentary structures, and the poor sorting and mixing of fine and coarse materials suggest that conglomerate (Gmm) was deposited by gravity flow and probably by debris flow deposits (debrites) which may be sub aerial as in alluvial fans (Tucker 1996). Sediments carried as debris flows are subjected to internal sorting processes. When the flow slows, the sorting may be preserved as graded bedding. Debris flow mechanisms are known to produce normal grading (Walker 1975) as it is described in the facies, matrix-supported conglomerates, as a result of debris-flow depositions, are quite commonly associated with many alluvial fans. The abundance of quartz pebble implies erosion and deposition over a long time period with a loss of unstable minerals. Similarities in compositions between matrix and clasts indicate intraformational oligomictic type of conglomerate. Angular to subrounded clasts suggest that the sources of sediments were proximal to the site of deposition.

Table 1: List of lithofacies identified in the Lifua Member, Manda Beds

Facies code	Lithofacies	Texture	Sedimentary structures	Interpretation
Gmm	Paraconglomerates	Massive, matrix supported paraconglomerate	Normal grading	Debris flow deposits
Sp	Planar cross-bedded sandstones	Sand, medium to course may be pebbly	Planar cross-bedded sandstone. Rootlet	Linguoid, transverse bars, sand waves (lower flow regime)
Sm	Massive sandstones	Massive sandstone	No structures	Due to rapid sedimentation
Sh	Parallel horizontal laminated sandstones	Sand, very fine to very course	Horizontal lamination parting or streaming lineation	Planar bed flow (lower and upper flow regime)
Fl	Silt, mud, clay	Silt, mud, clay	Finely laminated siltstone, mudstone and claystone with very small ripples.	Overbank or waning flood deposits

Massive sandstones (Sm)

These facies occur within the sandstone-rich sections and occasionally emanating from the top of the conglomerate facies in Masasi area. Grain sizes range from fine to coarse sandstones in beds of several centimetres to metres thick sheet like bodies. The sand grains are moderately sorted and are angular to subrounded. In some outcrops, pebbles and cobbles are scattered within the bed. These facies are friable and unconsolidated and do not show evidence of sedimentary structures. However, rootlets as fossils are present in some locations. The colour of the facies is made up of dark yellowish oranges (Plate 2).

Interpretation*:* The presence of variations in grain sizes (example cobbles and boulders) scattered within the bed and the absence of detectable internal sedimentary structures indicate that these facies were deposited due to rapid sedimentation (Cojan and Renard 2002). Sheet-like bodies of massive sandstones (Sm) indicate lower-flow regime bedforms and deposited in wide channel, which explains the preservation of these structures due to rapid depositions from heavy sediment-laden flows during waning floods (Maizels 1993). The predominantly massive sandstones indicate deposition took place from a hyper concentrated flow during abrupt changes in flow speed, caused by de-confinement or channel avulsion (Horn et al. 2018). The massive sandstone facies described here are interpreted as generated by abrupt deceleration of subaerial flows which produce structureless bed (Baas et al. 2011).

Planar cross-bedded sandstones (Sp)

These lithofacies are a major component of the sandstone rich fraction of the Lifua Member observed mainly at Sagaro. They consist mainly of small to medium scale planar cross-bedded sandstones with grain sizes ranging from medium to coarse (Plate 3). The thickness of beds ranges from a centimetre to few metres and linguoid in shape. The sandstones are moderately sorted, they are angular to sub-angular, consolidated and not well exposed. However, the area where the exposure was available, the colour was mainly very pale orange.

Interpretation: It is interpreted to be linguoid, transverse bars which formed during lower-flow regimes. Planar cross beds formed on the point bars of shallow streams (Williams 1966). Presence of planar cross beds indicates that sediments were deposited as mega ripples, which advanced due to water. Planar (tabular) cross-bedding is produced mainly by migration of large-scale, straight-crested (i.e., two dimensional) bedforms (Tucker 1996). It forms during lower-flow regimes. Small-scale planar cross bedding formed under unidirectional flow is associated almost entirely with the downstream migration of current ripples. The presence of mostly medium scale cross-strata sets formed by moving ripple indicates fluvial environment of deposition, but set thickness is also governed by the angle of climb of the bedform.

Parallel horizontal laminated sandstones (Sh)

These facies consist of alternating layers of mudstones and sandstone (Plate 4). They were observed mainly at Litumba-Kuhamba, Kipingu and Sagaro areas. These lithofacies are distinguished by having parallel laminations, thickly laminated and presence of mud/silt interbeds. The sizes of the sandstone grains are fine to coarse, rounded to subangular, and moderately sorted and the colour varies from dark yellowish orange to very pale orange. Rootlet fossils are present at some locations.

Interpretation:-The sandstones of this type of lithofacies are assumed to have been deposited from traction by high energy unidirectional currents under upper flow regime plane bed conditions, (see Cheel and Middleton 1986). The development of planar lamination caused by downstream movement of low-amplitude bed forms under upper-regime plane bed conditions (Smith 1971, Bridge and Best 1997). Planar-bedded deposits originated via upper flow regime under high deposition rates, resulting in thick lamination as described in the facies. Mud/silt interbeds and flat laminations show changes in velocity or fluctuations in stream power and sediment load within the channel. As the floodplain is a smaller than the channel, deposits of meandering river systems are dominated by moderately sorted and course-grained material; fine-grained floodplain tend to be relatively minor.

Silt, mud and clay (Fl)

These lithofacies consist of laminated siltstones and massive mudstone with sedimentary structures that are not clear. The muddy layers are mottled, orange, pink and red, with root traces (Plate 5) observed at Lukali. Trace fossils like animal burrows are present as well as roots. The upper half or upper third of these facies are invariably intensely bioturbated. The bioturbation consists of irregular tubes of about 4 to 7 mm diameter transecting the sandstone at various angles to the bedding. The basal sandstones of a "cyclothem" generally rest with a sharp boundary on the underlying multi-coloured mudstones (Wopfner et al. 1991).

Interpretation: It is interpreted to be overbank or waning flood deposits because the facies are made up of finely laminated siltstone, mudstone and claystone with very small ripples. Suspension is believed to be the most dominant processes for deposition of sediments of these facies, but also by low velocity unidirectional currents as evidenced by bioturbated nature of sediments. The rate of sedimentation was generally low during over bank deposits as evidenced by abundance of trace fossils and rootlets. In period of low water level, there was conversion of ferrous to the ferric state due to oxygenation through burrows resulting into mottling of muddy layer. Mottling may be due to bioturbation and differential colouring of burrows and non-bioturbated sediments or it may due to pedogenic processes (Tucker 1996).

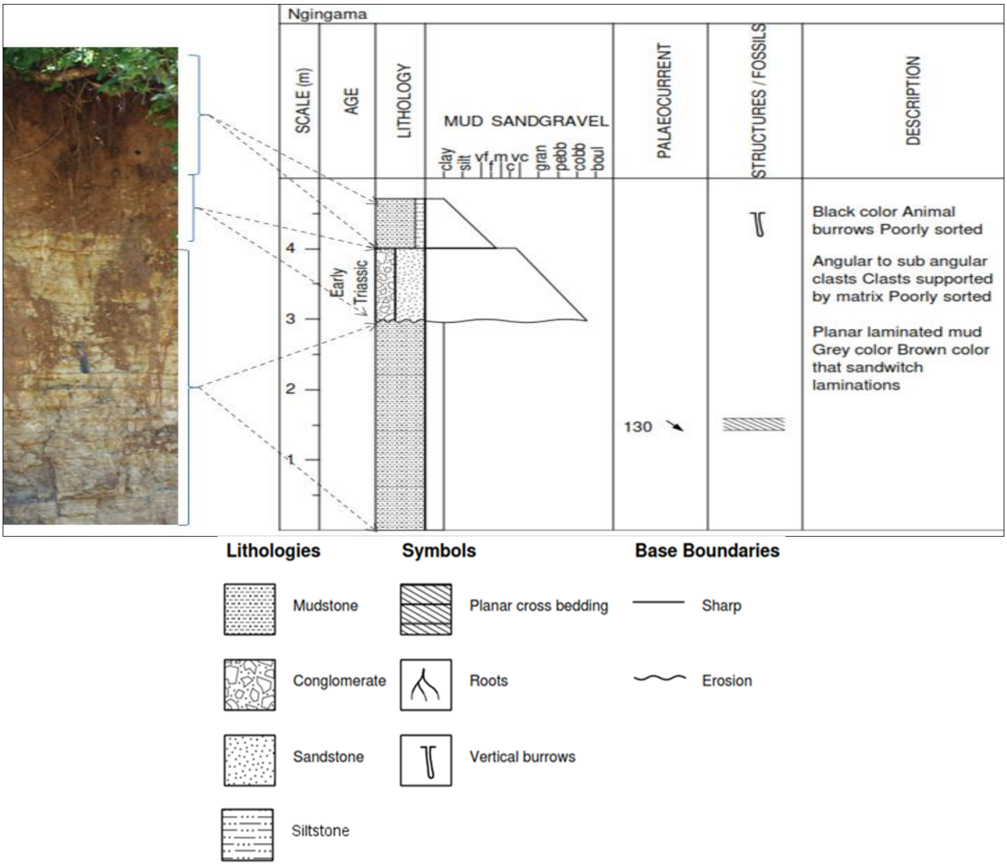


Figure 3: Ngingama river bank showing sandstone and mudstone facies.

Paleocurrent analysis

Paleocurrent analysis is primarily an outcrop study and useful for metals and other types of mining which deal with surface or large underground outcrops. In the present investigation, this technique was used for detection of current direction and sediment supply. Cross bedding is one of the best structures to determine paleocurrent direction. The azimuth values measured from the planar cross-beds exposed in Ntimbili River, Kipingu River, Lituhi, Sagaro, Manda, Mbondela, Lituhi, Lukali, Kihuru, Ngingama, Lihagule, Litumba Kuhamba, Kipingu and Masasi areas. Frequency distribution table with a range of (0-360°) was constructed using a class interval of 30°. The individual azimuths were tallied and the frequency of each interval is recorded in Table 2. After grouping, the data were used to plot Rose diagrams. The modal class indicates the direction in which the current has dominantly moved. The average structural dip of the study area is less than 20° and this may be due to the fact that, the area has not been much tectonically affected, and therefore no structural corrections were made.

Composite diagram for all of the readings of the study area is presented in Figure 4; it has only the current direction readings because no data were collected from structures with current sense (trend). This kind of Rose diagrams is called unimodal because it has one dominant source direction which is to the South/East. However, there are minor source directions such as to the North/West and South/West.

This trend is in agreement with the thickening of sandstones in a South-East direction. This trend also agrees with the graben that is between the Southern-Eastern part and the Northern-Western part of the Lifua Member. The deviations of the azimuth values that result into complexity of the Rose diagram indicate that, while a general current direction prevailed over the basin, local current directions also occurred.

Plate 1: Paraconglomerates (Gms).

Plate 2: Massive sandstones (Sm).

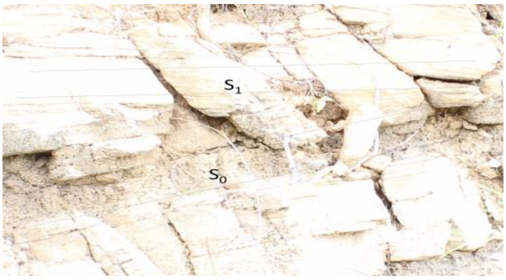


Plate 3: Cross-bedded sandstones (Sp), S0 is the bedding plane and S_1 stands for the planar cross-beds.

Plate 4: Alternative layers of mud and sandstones.

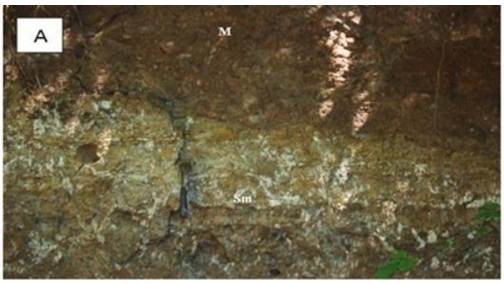


Plate 5: Silt, mud, clay (Fl). A: Clear demarcation between massive sandstones (Sm) and mudstones (M) located at Ngingama; B: Laminated siltstone located at Mbondela Lituhi.

Table 2: Azimuth data arranged in an interval of 30°

S/N	Class interval	No. of readings (Frequency)
1	0-30	0
2	30-60	0
3	60-90	3
4	90-120	10
5	120-150	11
6	150-180	12
7	180-210	1
8	210-240	7
9	240-270	7
10	270-300	5
11	300-330	3
12	330-360	9

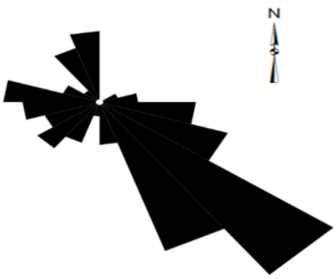


Figure 4: Composite Rose diagram of all current readings of the Lifua Member.

Grain size distribution

Sieving analysis was conducted for nine samples of gravel free sediments, the statistics results of which are presented in Table 3. The sieving error was 0.0% in all the samples. The mean sizes of the grains ranged from 2.2ϕ to 2.5ϕ, which implies fine sand, standard deviations ranged between 0.8ϕ and 1.2ϕ which signified moderately sorted, skewness between 0.02ϕ and 0.27ϕ which is fine skewed or positively skewed, kurtosis between 0.88ϕ and 1.13ϕ which implies that the distribution is mesokurtic (normal). The four parameters suggest unimodal distribution with exception to sample number 15 that portrayed bimodal distribution, probably due to poor sorting of the grains.

These four size parameters were plotted against each other in scatter diagrams in order to give geological significance of the Lifua Member. Textural classification according to Folk et al. (1970) shows that the Lifua Member is mainly made up of silty sand. Bivariate scatter plots in accordance with Friedman (1969) and Folk et al. (1970) suggest that the Lifua Member sandstone is of river sand (Figure 5) and the grain sorting variations suggest river energy level fluctuations and sediment depositions were not continuously reworked.

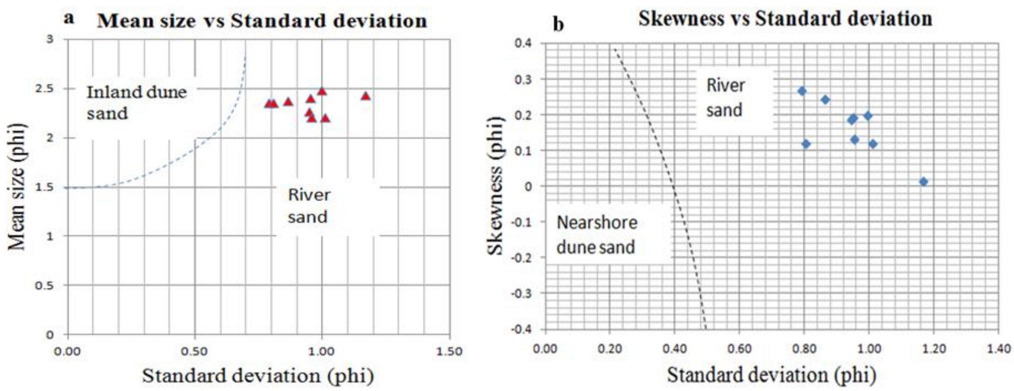


Figure 5: Depositional environment discrimination of Lifua Member (redrawn from Friedman 1969).

Table 3: Sample sieving statistics

Methods of grain size analysis	Grain size parameters	Samples								
		SMP15	**SMP18**	**SMP2**	**SMP19**	**SMP9**	**SMP5**	**SMP3**	**SMP12**	**SMP6**
Granulometry	Sample type	Bimodal, poorly sorted	Unimodal, moderately sorted	Unimodal, moderately sorted	Unimodal, moderately sorted	Unimodal, moderately sorted	Unimodal, moderately sorted	Unimodal, poorly sorted	Unimodal, moderately sorted	Unimodal, moderately sorted
	Textural group	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand
	Sediment name	Poorly sorted medium sand	Moderately sorted fine sand	Moderately sorted medium sand	Moderately sorted fine sand	Moderately sorted medium sand	Moderately sorted medium sand	Poorly sorted medium sand	Moderately sorted fine sand	Moderately sorted medium sand
Method of Moments Arithmetic (Mm)	Mean	165.0	210.1	198.6	206.4	198.3	204.4	206.2	203.8	210.9
	Sorting	113.4	95.22	116.2	101.0	109.7	114.2	122.9	101.7	119.8
	Skewness	0.366	0.055	0.322	0.198	0.179	–0.008	0.118	0.064	0.056
	Kurtosis	2.417	2.594	2.289	2.699	2.418	2.360	2.232	2.496	2.295
Method of Moments Geometric (Mm)	Mean	80.27	165.5	134.3	151.4	131.6	122.5	117.1	147.6	125.6
	Sorting	6.007	2.462	3.424	3.044	3.712	4.650	5.039	3.087	4.717
	Skewness	–1.785	–3.849	–2.812	–3.443	–2.814	–2.449	–2.273	–3.291	–2.441
	Kurtosis	4.807	22.02	11.73	15.93	10.89	8.012	7.078	14.94	7.968
Method of Moments Logarithmic (ϕ)	Mean	2.329	2.385	2.437	2.343	2.365	2.203	2.167	2.377	2.158
	Sorting	1.205	0.802	1.011	0.843	0.977	1.002	1.040	0.891	0.994
	Skewness	–0.451	0.128	–0.163	–0.289	–0.235	–0.233	–0.243	–0.103	–0.253
	Kurtosis	2.624	3.733	2.838	3.842	3.240	3.243	2.939	3.559	3.108
Folk and Ward Method (Mm)	Mean	184.6	194.9	179.0	195.3	188.1	207.3	215.5	191.9	216.1
	Sorting	2.245	1.728	1.990	1.746	1.931	1.925	2.012	1.819	1.938
	Skewness	–0.015	–0.268	–0.201	–0.123	–0.195	–0.189	–0.123	–0.245	–0.132
	Kurtosis	1.044	0.970	0.875	0.959	1.005	1.132	1.042	0.997	1.034
Folk and Ward Method (F)	Mean	2.438	2.359	2.482	2.357	2.411	2.271	2.214	2.382	2.211
	Sorting	1.167	0.789	0.993	0.804	0.949	0.945	1.008	0.863	0.954
	Skewness	0.015	0.268	0.201	0.123	0.195	0.189	0.123	0.245	0.132
	Kurtosis	1.044	0.970	0.875	0.959	1.005	1.132	1.042	0.997	1.034
Folk and Ward Method (Description)	Mean	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand
	Sorting	Poorly sorted	Moderately sorted	Moderately sorted	Moderately sorted	Moderately sorted	Moderately sorted	Poorly sorted	Moderately sorted	Moderately sorted
	Skewness	Symmetrical	Fine skewed	Fine skewed	Fine skewed	Fine skewed	Fine skewed	Fine skewed	Fine skewed	Fine skewed
	Kurtosis	Mesokurtic	Mesokurtic	Platykurtic	Mesokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Mesokurtic	Mesokurtic
	Mode 1 (mm)	283.5	283.5	283.5	283.5	283.5	283.5	283.5	283.5	283.5
	Mode 2 (mm)	60.00								
	Mode 1 (f)	1.866	1.866	1.866	1.866	1.866	1.866	1.866	1.866	1.866

Table 3 (ctd): Sample sieving statistics

Grain size parameters		Samples								
		SMP15	SMP18	SMP2	SMP19	SMP9	SMP5	SMP3	SMP12	SMP6
	Mode 2 (f)	4.105								
	D_{10} (mm)	64.58	85.67	67.81	90.82	75.39	83.20	83.92	79.40	88.08
	D_{50} (mm)	192.1	212.0	199.5	204.8	208.7	230.5	232.3	212.0	234.8
	D_{90} (mm)	542.8	341.9	413.3	362.2	404.3	463.9	489.8	351.1	475.8
	(D_{90} / D_{10}) (mm):	8.406	3.990	6.096	3.988	5.363	5.576	5.837	4.423	5.402
	(D_{90} - D_{10}) (mm):	478.2	256.2	345.5	271.3	329.0	380.7	405.9	271.7	387.7
	(D_{75} / D_{25}) (mm)	2.839	2.188	2.790	2.233	2.480	2.347	2.532	2.311	2.420
	(D_{75} – D_{25}) (mm)	201.6	155.1	192.9	160.5	178.1	181.9	202.4	164.9	193.5
	D_{10} (f)	0.882	1.549	1.275	1.465	1.306	1.108	1.030	1.510	1.072
	D_{50} (f)	2.380	2.238	2.326	2.288	2.260	2.117	2.106	2.238	2.090
	D_{90} (f)	3.953	3.545	3.882	3.461	3.729	3.587	3.575	3.655	3.505
	(D_{90} / D_{10}) (f)	4.484	2.289	3.046	2.362	2.855	3.237	3.472	2.421	3.271
	(D_{90} – D_{10}) (f):	3.071	1.996	2.608	1.996	2.423	2.479	2.545	2.145	2.433
	(D_{75} / D_{25}) (f)	1.894	1.625	1.854	1.650	1.751	1.743	1.848	1.678	1.796
	(D_{75} – D_{25}) (f)	1.505	1.129	1.480	1.159	1.311	1.231	1.340	1.209	1.275
	% Gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Sand	90.9	95.3	92.0	96.5	93.7	95.0	95.5	94.4	96.4
	% Mud	9.1	4.7	8.0	3.5	6.3	5.0	4.5	5.6	3.6
	% V coarse gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Coarse gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Medium gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Fine gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% V fine gravel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% V coarse sand	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Coarse sand	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Medium sand	36.8	36.2	36.9	36.0	37.6	43.6	45.0	36.9	45.4
	% Fine sand	32.4	41.1	32.1	41.2	35.7	34.5	32.2	38.4	33.0
	% V Fine sand	21.8	18.0	23.0	19.2	20.4	16.8	18.3	19.2	18.0
	% V coarse silt	9.1	4.7	8.0	3.5	6.3	5.0	4.5	5.6	3.6
	% Coarse silt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Medium silt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Fine silt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% V fine silt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% Clay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Conclusion

Sedimentological and paleocurrent analyses have been conducted on the early Triassic strata in order to determine their depositional environments. Present investigations include integrated study of facies analysis, paleocurrent measurements and granulometric analysis. The lithofacies of the Lifua Member varies from massive matrix supported paraconglomerate (Gmm), massive sandstone (Sm), parallel-horizontal laminated sandstone (Sh), planar cross bedded sandstone (Sp) and fine silt mud and clay (Fl) governed mostly by normal grading. Dominant sedimentary structures are planar cross-bedding, horizontal laminations and minor ripples observed mostly in the fine sand, silt and mud. Fining upward sequence of most of the sandstone facies is indicating clearly fluviatile environment dominated by sand channel deposition, which also implies loose of energy of the river current as sediments were advancing down-slope. Differences in stacking patterns and variability in grain size and the presence/absence of fine-grained facies indicate the existence of meandering rivers probably sandy rivers with thin fine member.

Paleocurrent data show a typically narrow range of directions striking to south-east although some show variability in direction from various localized area. Strong unimodal character of paleocurrent data suggests a fluvial environment of deposition.

Grain size analysis of the gravel free sandstones indicated that the Lifua Member sandstones are moderately sorted, finely skewed, mesokurtic and most of the grains are silty sand. Bivariate scatter plots suggest that the Lifua Member sandstone is of river sand. Thus on the basis of lithofacies, palaeocurrent and grain size studies, it is concluded that fluvial environment was dominated by sand channel deposits.

Acknowledgements

Authors wish to thank the reviewers for improving the quality of research paper by making constructive comments and also thankful to the Geological Survey of Tanzania (GST) Dodoma for providing necessary laboratory facilities.

References

Barrett PM, Nesbit SJ and Peecook BR 2015 A large-bodied silesaurid from the Lifua Member of the Manda beds (Middle Triassic) of Tanzania and its implications for body-size evolution in Dinosauromorpha. *Gondwana Res.* 27(3): 925-931.

Baas JH, Best JL and Peakall J 2011 Depositional processes, bedform development and hybrid bed formation in rapidly decelerated cohesive (mud–sand) sediment flows. *Sedimentology* 58(7): 1953-1987.

Bridge J and Best J 1997 Preservation of planar laminae due to migration of low-relief bed waves over aggrading upper-stage plane beds: comparison of experimental data and theory. *Sedimentology* 44: 253-262.

Catuneanu OW, Wopfner H, Eriksson PG, Cairncross B, Rubidge BS, Smith RMH and Hancox PJ 2005 The Karoo basins of South-central Africa. *J. Afr. Earth Sci.* 43: 211-253.

Charig AJ 1957 New Triassic Archosaurs from Tanganyika, including Mandasuchus and Teleocrater. PhD Dissertation Abstract, Cambridge University, p. 278.

Cheel RJ and Middleton GV 1986 Horizontal laminae formed under upper flow regimeplane bed conditions. *J. Geol.* 94: 489-504.

Cojan I and Renard M 2002 Sedimentology. 1st edition, Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, India.

Douglas Lake Minerals Inc. 2011 Quarterly Report on Form 10-Q for the Quarterly Period Ended August 31, 2011, submitted to United States Securities and Exchange Commission, Washington DC 20549 in October 2011. [Retrieved from www.handenigold.com January 19, 2017].

Folk RL, Andrews PB and Lewis DW 1970 Detrital sedimentary rock classification and nomenclature for use in New Zealand. *N. Z. J. Geol. Geophys*. 13: 937-968.

Friedman GM 1969 Differences in size distribution of populations of particles among sands of various origins. *Sedimentology* 26: 859-862.

Horn BLD, Goldberg K and Schultz CL 2018 Interpretation of massive sandstones in ephemeral fluvial settings: A case study from the Upper Candelária Sequence (Upper Triassic, Paraná Basin, Brazil). *J. South Am. Earth Sci.* 81: 108-121.

Kreuser T, Wopfner H, Kaaya CZ, Markwort S, Semkiwa PM and Asladisi P 1990 Depositional evolution of a Permo-Triassic Karoo basin in Tanzania with reference to their economic potential. *J. Afr. Earth Sci.* 10: 151-167.

Maizels J 1993 Lithofacies variations within sandur deposits: the role of runoff regime, flow dynamics and sediment supply characteristics. *Sediment Geol.* 85(1–4): 299-325.

Miall AD 1978 Lithofacies types and vertical profile models in braided river deposits. *Canad. Soc. Petrol. Geol. Mem.* 5: 597-604.

Miall AD 1996 The Geology of fluvial deposits, Sedimentary facies, Basin Analysis, and Petroleum Geology. 4th corrected printing, Springer-Verlag Germany.

Mtelela C, Roberts ME, Downie R and Hendrix SM 2016 Interplay of structural, climatic and volcanic controls on late Quartenary lacustrine-deltaic sedimentation patterns in the Western Branch of the East Africa Rift System, Rukwa Rift Basin, Tanzania. *J. Sediment. Res.* 86(10): 1179-2107.

Nesbitt SJ, Sidor CA, Angielczyk KD, Smith RM and Tsuji LA 2014 A New Archosaur from the Manda Beds (Anisian, Middle Triassic) of Southern Tanzania and its implications for character state optimizations at Archosauria and Pseudosuchia. *J. Vertebr. Paleontol.* 34: 1357-1382.

Selley RC 2000 Applied sedimentology, 2nd edition, A Harcourt Science and Technology Company, San Diego, California USA.

Semkiwa PM 1992 Depositional environment and coal petrography of Permian coal deposits in Karoo Basins of SW Tanzania. Sonderveröffentlichungen (Vol. 84, p. 186), Geologisches Institut Universität zu Köln.

Smith ND 1971 Pseudo-planar stratification produced by very low amplitude sand waves: *J. Sediment. Res.* 41: 69-73.

Stockley GM and Oates F 1937 Report on the Geology of Ruhuhu Coalfields.

Tucker ME 1996 Sedimentary rocks in the field. 2nd edition, John Wiley and Sons, Ltd, United Kingdom.

Tucker ME 2003 Sedimentary rocks in the field. 3rd edition, John Wiley and Sons, Ltd, United Kingdom.

Walker RG 1975 Generalized facies models for resedimented conglomerates of turbidite association. *Geol. Soc. Am. Bull*. 86: 737-748.

Williams GE 1966 Planar cross-stratification formed by the lateral migration of shallow streams. *J. Sediment. Res.* 36(3): 742-746.

Wopfner H, Markwort S and Semkiwa PM 1991 Early diagenetic Laumontite in the lower Triassic Manda Beds of the Ruhuhu Basin, Southern Tanzania. *J. Sedimentary Res.* 61: 65-72.