

Revised stratigraphy and age of the Red Sandstone Group in the Rukwa Rift Basin, Tanzania

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Abstract

The Red Sandstone Group comprises a succession of red sandstones and mudstones exposed in the Rukwa and Malawi rift basins of southwestern Tanzania and northern Malawi. Stratigraphic, sedimentologic, and paleontologic investigations of the Red Sandstone Group in the Songwe Basin (a sub-basin of the Rukwa Rift Basin) help clarify the age and depositional history of these strata, which have previously been assigned ages ranging from Middle Jurassic to late Miocene. These seemingly incompatible Mesozoic and Tertiary age assignments for the Red Sandstone Group are, in part, explained by our discovery of two distinct units (Units I and II) that are of different ages but composed of lithologically similar red sandstones and mudstones in the Songwe Basin. Based on distinct, temporally limited vertebrate fossil remains, a Cretaceous age is proposed for Unit I and a Paleogene age for Unit II. The identification of different-aged units in the Songwe Basin suggests a complex structural and stratigraphic history for the Red Sandstone Group in the context of East African Rift evolution.

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1. Introduction

The Rukwa Rift Basin in southwestern Tanzania contains up to 11 km of Permian to Holocene sedimentary fill, making it the thickest package of sedimentary strata in the East African Rift System (EARS) (Wheeler and Karson, 1994), and the subject of recent exploration to assess its potential as a petroleum-producing basin (see Morley et al., 1999). A number of workers have sought to better characterize the complex structural and stratigraphic history of the basin, and a considerable

amount of debate has been generated concerning the exact nature and timing of tectonic and depositional events in the rift (e.g., Ebinger et al., 1989; Wescott et al., 1991; Kilembe and Rosendahl, 1992; Wheeler and Karson, 1994; van der Beek et al., 1998). Particularly problematic are the inconsistent nomenclature and variable age assignments of red sandstones and mudstones which crop out below the Pliocene–Holocene East African Rift strata (Lake Beds sensu Grantham, 1932) and above the upper Paleozoic and lower Mesozoic strata of the Karoo Supergroup. The name “Red Sandstones” was originally used by Spence (1954) to describe the series of red sandstones and mudstones exposed near the Galula coalfields (see Fig. 1), although a formal type section with a detailed description was

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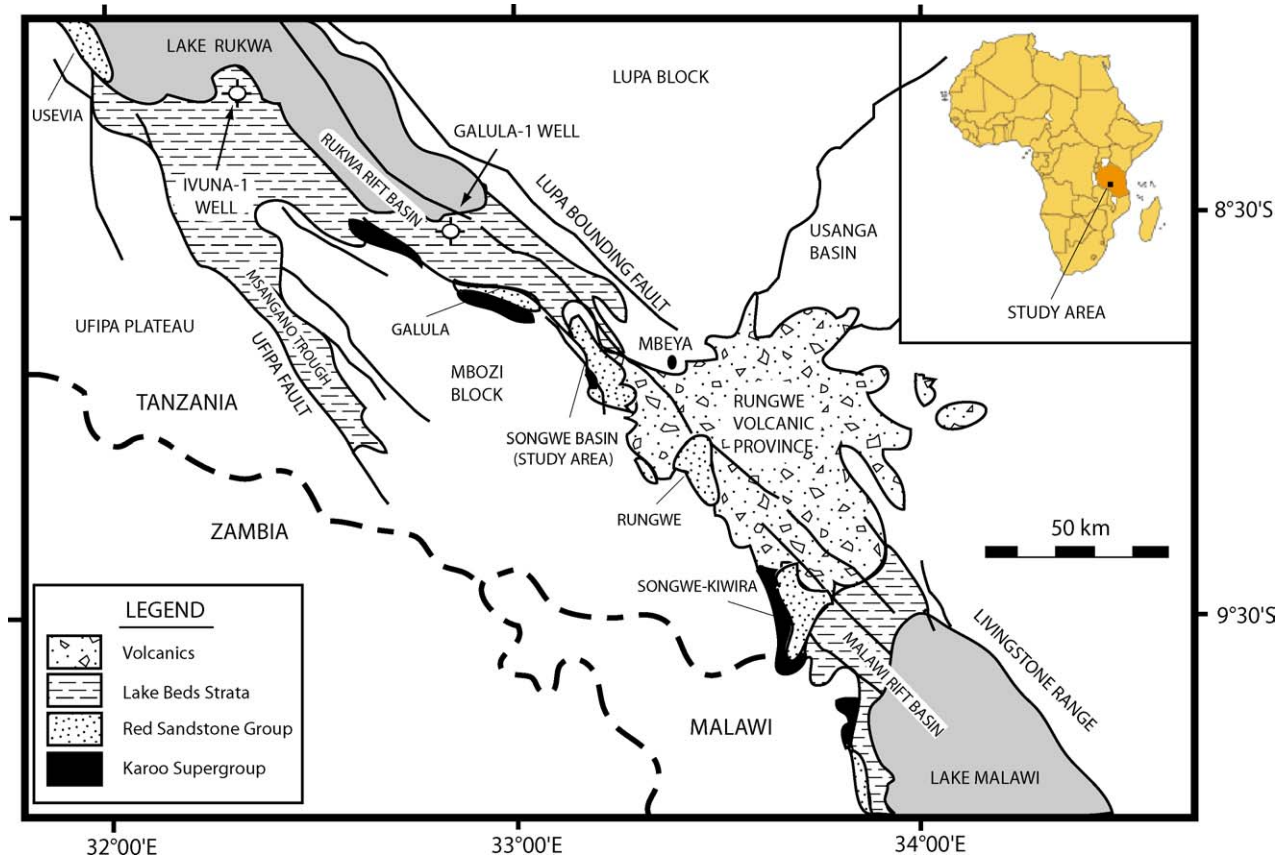


Fig. 1. Location of the Rukwa Rift Basin and the major areas in which the Red Sandstone Group is exposed in southwestern Tanzania (modified from Damblon et al., 1998).

never presented. Numerous names have been applied to this sedimentary succession since Spence's (1954) work, including: the "Red Beds" (Pentelkov, 1979); the "Red Bed Sandstone Sequence" or the "Red Bed Sandstone Formation" (Kilembe and Rosendahl, 1992); the "Red Sandstone Formation" (Wescott et al., 1991); and the "Red Sandstone Group" (Dypvik et al., 1990; Damblon et al., 1998; Morley et al., 1999). The isolated nature of outcrop belts in which these strata are exposed, and the considerable variation in lithologies that exists between these belts, are further complicating factors (Dypvik et al., 1990). We follow Dypvik et al. (1990) and others and use the term Red Sandstone Group for all exposures of red sandstones and mudstones that are stratigraphically between the Karoo Supergroup and the Lake Beds strata.

A more serious problem relates to the age of Red Sandstone Group strata within the region. Proposed ages range from Middle Jurassic to late Miocene (Fig. 2). Spence (1954) and others (e.g., Spurr, 1954; Grantham et al., 1958) originally considered the Red Sandstone Group to be Cretaceous based upon lithological similarities with Cretaceous dinosaur-bearing beds in Malawi (Dixey, 1928; Jacobs et al., 1990). Quennell et al. (1956) and later Pentelkov (1979)

suggested a Late Jurassic age based on long-range lithological correlations with well-dated red beds exposed along the southern coast of Tanzania and Mozambique. Several other workers have proposed ages between Middle Jurassic and Early Cretaceous based on unidentified reptile bone fragments near Galula (Pallister, 1963), fossil dinosaur eggs along the Songwe River (Swinton, 1950), "relics of mollusks and reptiles" near Usevia (Smirnov et al., 1974), and stratigraphic relationships with intrusive carbonatites near Mbeya (Pentelkov and Voronovskii, 1977).

Recent investigations by the AMOCO Production Company (e.g., drilling of two hydrocarbon exploration wells: Ivuna-1 and Galula-1; see Fig. 1) have added to the debate about the age of the Red Sandstone Group (see Morley et al., 1999). Based upon palynological assemblages recovered from sidewall cores and cuttings from both the Ivuna-1 and Galula-1 wells, Wescott et al. (1991) reported a Miocene–Pliocene age for the Red Sandstone Group on the basis of a sparse number of the diatoms *Melosira granulata* and/or *M. agassizii* (Fig. 2). Both species are known from the upper Miocene–Holocene of Africa and are typically found in freshwater (lacustrine) environments with high dissolved silica levels (Wescott et al., 1991). However, Kilembe and Rosendahl (1992)

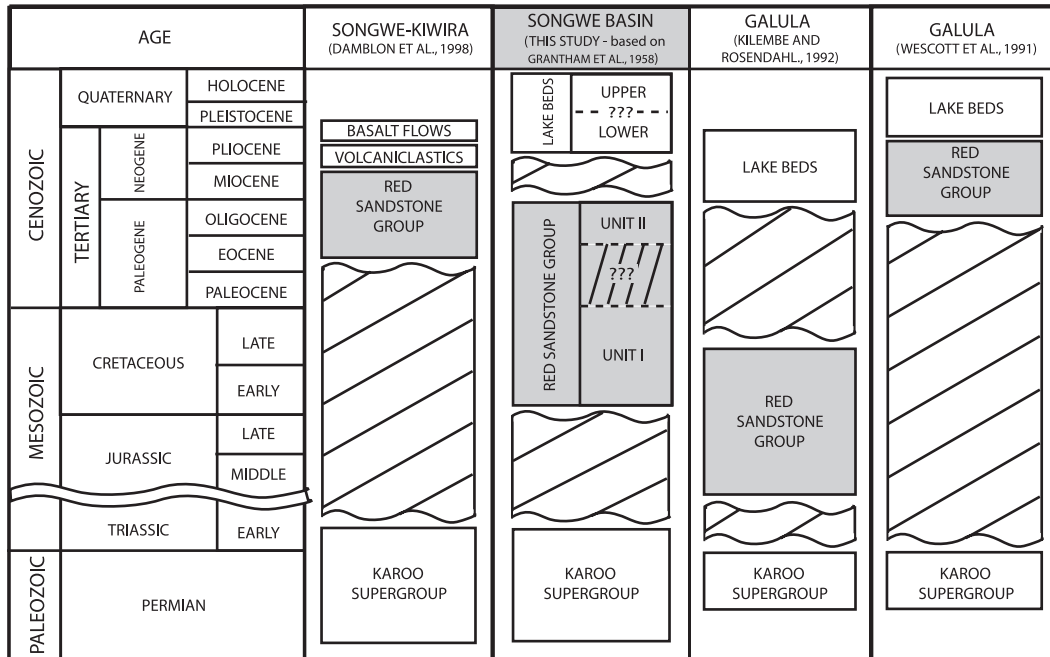


Fig. 2. Recent stratigraphic interpretations for the Rukwa and northern Malawi rift basins. Results from this study (Songwe Basin) are highlighted in gray.

also examined cuttings from the same two wells and failed to document the presence of *Melosira*. They did, however, find rare examples of the wind-blown pollen *Classopollis classoides* and *Callialasporites dampieri*, which suggest a Middle Jurassic–middle Cretaceous age for these deposits (Fig. 2; Kilembe and Rosendahl, 1992). Morley et al. (1999) favored a Neogene age for the group, noting that the pollen grains reported by Kilembe and Rosendahl (1992) are also found in the Cretaceous bentonite used as drilling mud in the two wells, and is thus a contaminant. Most recently, Damblon et al. (1998) identified a small fragment of silicified fossil wood (from near the Songwe-Kiwira coal mines just north of the Malawi border) as *Pahudioxylon*, a taxon restricted to the late Cenozoic, lending additional support to other assessments of a Neogene age for the Red Sandstone Group (Fig. 2).

In light of these problems, we present definitive new evidence on the age of the Red Sandstone Group in the Songwe Basin region of the Rukwa Rift. Structural, stratigraphic, and paleontologic evidence collected in the Songwe Basin reveals the existence of two lithologically similar units, one Cretaceous and one Tertiary, which crop out within several kilometers of each other. These new data help to delineate and clarify critical aspects of stratigraphy and basin evolution in the Rukwa Rift.

2. Geologic setting/context

The Rukwa Rift is a roughly 300 km long by 50 km wide, northwest–southeast-trending segment of the

Western Branch of the East African Rift System, located in southwestern Tanzania between Lakes Tanganyika and Nyasa (Malawi) (Fig. 1). Much of the basin is currently occupied by Lake Rukwa, a shallow (<15 m deep) lake fed by the Songwe and Momba rivers from the south and the Kavu and Rungwe rivers from the north. Structurally, the Rukwa Rift displays classic half-graben architecture, flanked by uplifted Precambrian Pan-African metamorphic rocks (Kilembe and Rosendahl, 1992). The rift basin is bound by the Ufipa fault and plateau to the southwest, the Lupa fault to the northeast, the Ubende plateau to the north, and the Mbozi block and Rungwe volcanics to the south (Ebinger et al., 1989; Kilembe and Rosendahl, 1992). Significantly, the Rukwa Rift follows the trend of Precambrian basement foliation, and various workers (e.g., Kilembe and Rosendahl, 1992; Wheeler and Karson, 1994) have demonstrated a minimum of three distinct phases of tectonic activity, beginning in the Permian.

Three major stratigraphic sequences have been delineated in the Rukwa Rift Basin, each correlated with separate tectonic events between the Permian and Holocene. However, the exact timing and structural regime associated with these rifting events is debatable. Specifically, the mechanism of basin development in the Rukwa Rift has been described variously as purely extensional, purely strike-slip, and some combination of the two styles (Ebinger et al., 1989; Kilembe and Rosendahl, 1992; Wheeler and Karson, 1994).

2.1. Karoo Supergroup

The timing of Permian tectonism and basin development is well documented and generally non-contentious (van der Beek et al., 1998). This event was related to the break-up of Pangaea, and resulted in the initial deposition of Karoo sediments in the Rukwa Rift Basin and widespread deposition in other well-known Karoo basins across southern Africa, Madagascar, and South America (Wopfner, 2002). The Karoo Supergroup in the Rukwa Rift is composed of a series of glacial, lacustrine, and fluvial deposits of Permian–Triassic age. These units are dominated by oxidized mudstones and sandstones, conglomerates, carbonates and coals (Dypvik et al., 1990).

2.2. Red Sandstone Group

The Red Sandstone Group lies with angular unconformity on the Karoo Supergroup, commonly exhibiting a dip angle of 10–30° (Dypvik et al., 1990). Deposition of the Red Sandstone Group was likely related to renewed tectonic activity along pre-existing basement structures, possibly associated with the break-up of Gondwanaland (Dypvik et al., 1990). Exposures of the Red Sandstone Group crop out in isolated exposure belts along the margin of the rift, and are known from the Songwe Basin (our primary field area), Galula (along the Tembo, Mtuka, and Chizi rivers), Usevia, and in the Songwe-Kiwira and Rungwe areas (both of which are actually located in the northern end of the Malawi Rift Basin) (Fig. 1). Although the latter two areas are not specifically within the Rukwa Rift Basin, they are thought to be correlative in age (Harkin and Harpum, 1957; Grantham et al., 1958; Dypvik et al., 1990). Each area is typified by differences in sandstone/mudstone ratios, paleocurrent direction, grain size, and fossil content and preservation (Dypvik et al., 1990).

The Red Sandstone Group is up to several hundred meters thick in outcrop, and sub-surface measurements exceed 900 m (Wescott et al., 1991; Kilembe and Rosendahl, 1992; Morley et al., 1999). Medium-grained, red-purple sandstone with occasional pebble lenses dominate much of the section; however, thin, lenticular red mudstones and siltstone are also common. Within and to the south of the Songwe-Kiwira area, Dixey (1928) and Dypvik et al. (1990) subdivided the group into lower and upper units. They documented a lower, coarse-grained, sandstone-conglomerate interval, overlain by a finer-grained upper unit dominated by marls, becoming sandier towards the north.

2.3. Lake beds sequence

The “Lake Beds” form the third major depositional sequence in the Rukwa Rift Basin, and are related to

late Tertiary–Pleistocene rifting associated with the modern East Africa Rift System (Quennell et al., 1956). Lake Beds strata are well exposed, particularly to the east of Galula; they are typically composed of unconsolidated alluvium, sand, mud and volcanic silt, and were deposited in fluvial, alluvial, and lacustrine depositional systems (Wescott et al., 1991; Kilembe and Rosendahl, 1992). The contact between the Lake Beds sequence and the underlying Red Sandstone Group is typically erosional (Ebinger et al., 1989). Grantham et al. (1958) subdivided the Lake Beds sequence into lower and upper units; however, detailed stratigraphic and facies relationships of the Lake Beds sequence are still poorly understood. Their age is generally well constrained, based on radiometric dating of intercalated ash beds and palynological analysis of core samples (Ebinger et al., 1989; Wescott et al., 1991).

3. Methods

Our data were collected during the austral winters of 2002 and 2003 as part of an exploratory project aimed at identifying Cretaceous vertebrate localities in southwestern Tanzania. The majority of the fieldwork was concentrated in the Songwe Basin, between the “Tanzam Highway” and the confluence of Longozi Creek with the Songwe River to the north (Fig. 3). Additional outcrops were examined in the Songwe-Kiwira and the Galula coalfield areas (along the Mtuka River) (Fig. 1). In addition to excavation and collection of fossil vertebrates, rocks were systematically collected for petrographic, radiometric, and palynological analysis. Seven detailed stratigraphic sections were measured in the Songwe Basin. Paleocurrent measurements were recorded on troughs of three-dimensionally exposed cross-beds. The Mbeya quarter-degree geological map produced by Grantham et al. (1958) was used as a base map for more detailed geological mapping. Extensive field investigations utilizing GPS and Brunton compass were employed to help clarify stratigraphic and structural complexities, particularly relating to the Red Sandstone Group.

4. Stratigraphy and sedimentology of the Red Sandstone Group in the Songwe Basin

Two different units, both mapped as Red Sandstone Group, were identified in the field area for the first time (Figs. 2–4). Herein, these are informally referred to as Unit I and Unit II. Unit I is best exposed along the Songwe River north of the Tanzam Highway, whereas Unit II is known from isolated exposures to the south of the highway (Fig. 3). Unit II exhibits minor lithological differences from Unit I; however, mammalian fossils

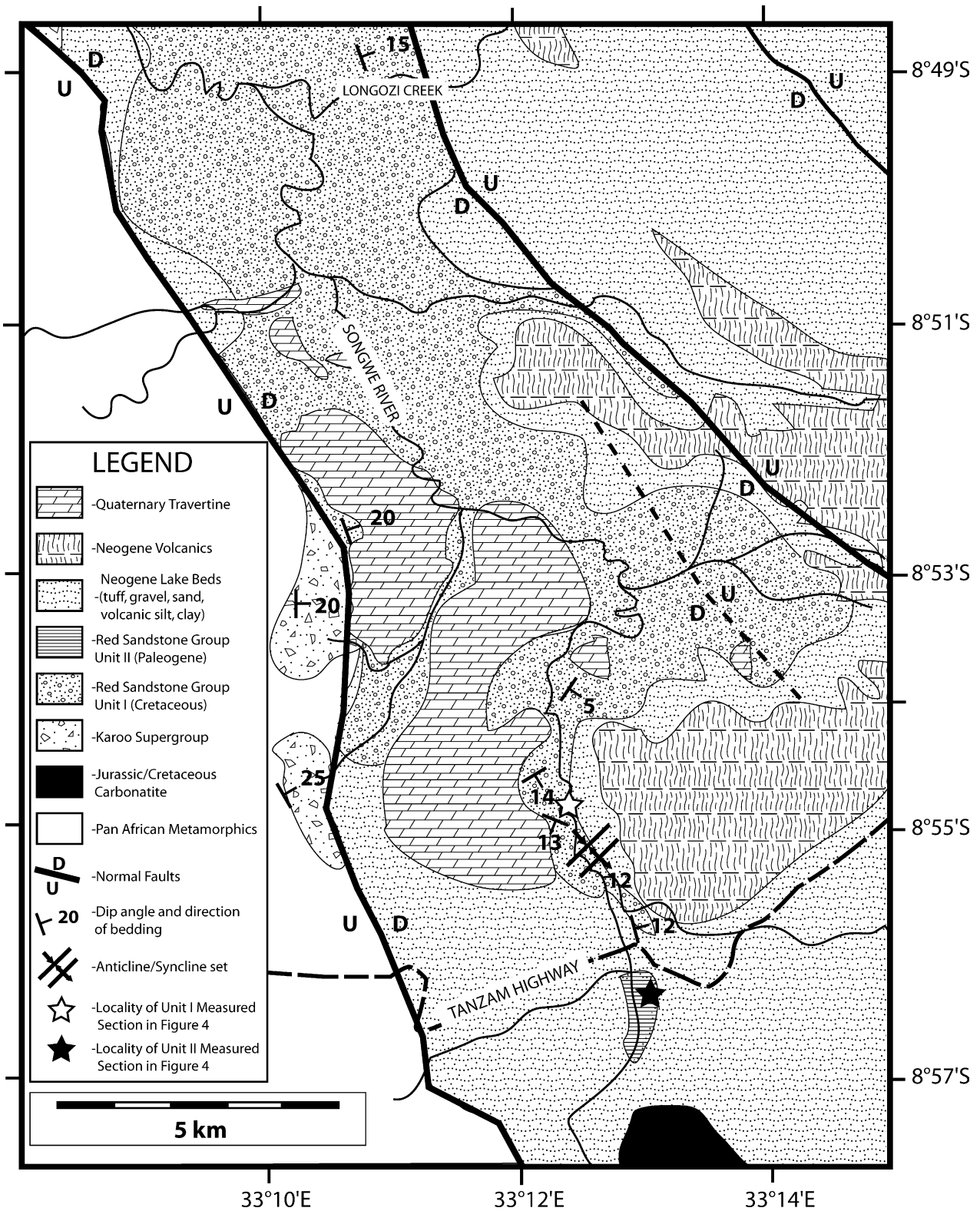


Fig. 3. Detailed geologic map of the Songwe Basin area showing the location of both Units I and II of the Red Sandstone Group, in addition to the other lithologic units and the structural features mapped in the field area (based on Grantham et al., 1958; Ebinger et al., 1989).

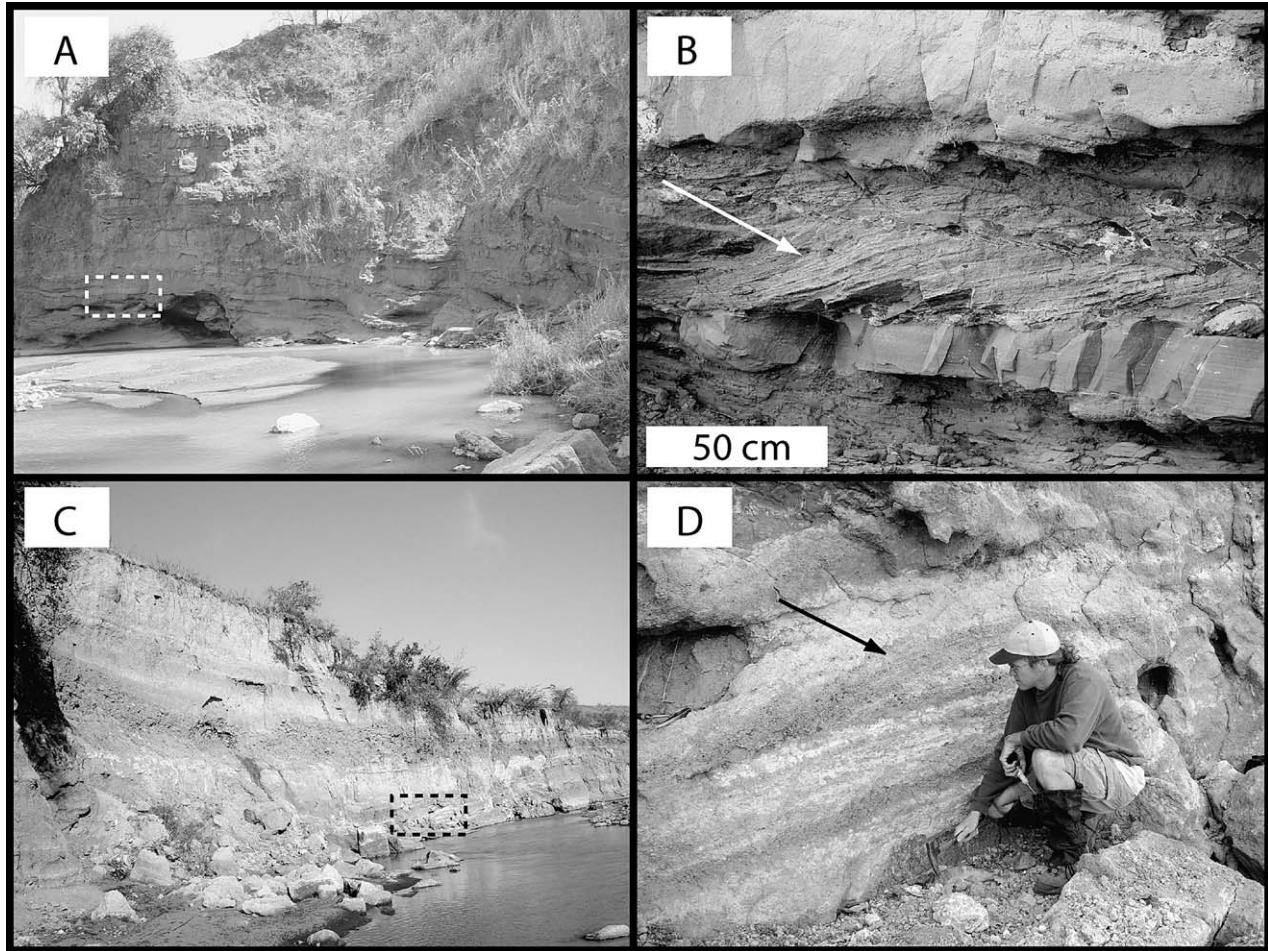


Fig. 4. Outcrop photographs of the Red Sandstone Group. A, typical outcrop exposure of Unit I along the Songwe River (cliff is ca. 18 m high) with box showing location of close-up in next photograph. B, close-up of Unit I showing medium-scale trough cross-bedding (arrow) and cut-and-fill architecture. C, typical outcrop exposure of Unit II along the Songwe River (cliff is ca. 15 m high) with box showing location of close-up in next photograph. D, close-up of light red and white, cross-bedded sandstone (arrow) of Unit II.

(e.g., multiple taxa of rodents) recovered from Unit II indicate a distinctly different, and clearly much younger, fauna than the Unit I beds that comprise the remainder of the Red Sandstone Group in the area. Early mapping work by [Grantham et al. \(1958\)](#) lumped both of these units together as Cretaceous “Red Sandstone”, but our new faunal evidence permits delineation of at least two temporally distinct lithological units in the Songwe Basin.

4.1. Observations, Unit I

Our proposed Unit I of the Red Sandstone Group is best exposed on the cutbank side of meander bends along the Songwe River. A series of small anticlines, synclines, and normal faults were mapped in the field area ([Fig. 3](#)). Dip angle and direction vary throughout the field area; however, the overall dip trend is 12–15° to the east. More than 140 m of nearly continuous outcrop

exposure has been mapped and measured in the Songwe Basin, but most outcrops are significantly thinner, ranging from 10 to 40 m ([Fig. 4](#)). A representative section is presented from the TZ-07 locality, which begins several meters above the Songwe River and extends to the top of the valley ([Fig. 5](#)). Throughout most of the field area, Unit I is unconformably overlain by a variety of different Neogene–Quaternary units; including travertine, volcanics, and Lake Beds strata (especially conglomerate, siltstone and volcanoclastics). Although Unit II is clearly younger than Unit I, an observable contact between the two units has yet to be identified in the field area. Both units have been measured along the Songwe River at similar topographic levels ca. 2–3 km apart, suggesting that the contact is either fault bounded or erosional. Based on the field relationships, subtle differences in lithology and major differences in faunas, it appears unlikely that the upper unfossiliferous beds of Unit I are correlative or conformable with Unit II strata ([Fig. 5](#)).

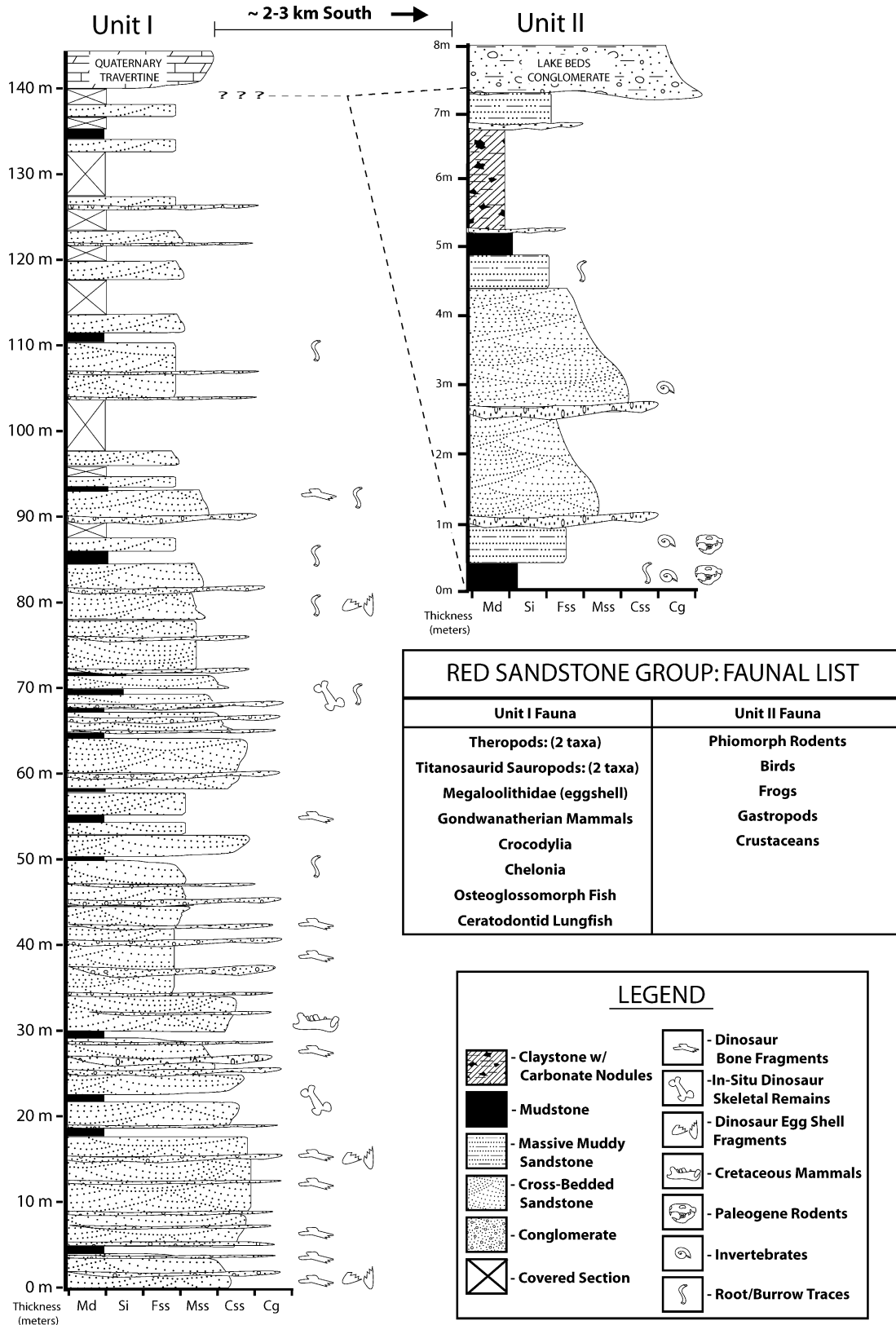


Fig. 5. Stratigraphic sections of Units I and II of the Red Sandstone Group in the Songwe Basin measured at the TZ-07 and TZ-01 fossil localities, respectively. Dense vegetation and topographic features prohibit direct stratigraphic correlation between the two localities. Md, mudstone; Si, siltstone; Fss, fine sandstone; Mss, medium sandstone; Css, coarse sandstone; cg, conglomerate.

Unit I is dominated by thick sequences of deep red (5R 2/6), pale red-purple (5RP 6/2), and grayish purple (5P 4/2) sandstones (Figs. 4, 5) which are poorly–moderately sorted, fine–very coarse-grained and well cemented. Trough cross-stratification is the most common sedimentary structure observed, but tabular cross-stratification and planar bedding are also present. Cross-bed sets range from small- to large-scale. Pebble lenses 3–35 cm thick are common along the basal surface of sandstone beds, particularly in the lower 50–75 m of the section. The upper 75–100 m of the section is finer-grained, with fewer pebble lenses. Petrographic analysis reveals both texturally and compositionally immature sandstones, dominated by quartz (ca. 70%), potassium feldspar (ca. 20%), lithic and metamorphic rock fragments (ca. 10%), and clay matrix. Pebble lenses are clast supported and dominated by intra-formational mudstone rip-up clasts (ca. 50–70%), metamorphic rock fragments (20%), lithic rock fragments (ca. 5–10%), minor bone fragments (<5%), and minimal matrix. Sandstones are highly amalgamated and composed of stacked, fining-upward beds ranging from 0.2–3 m thick. Individual beds are lenticular to tabular, with abundant erosional truncation and scour surfaces. Paleocurrent measurements taken from throughout the section and at numerous separate localities are remarkably consistent, showing flow to the northwest with a mean azimuth of 294° (n = 68).

Dark red (5R 2/6) mudstone and siltstone beds comprise ca. 10% of Unit I. These beds are commonly thin (<1 m), lenticular, and truncated by sandstone beds. Rare trace fossils (*Skolithos* and *Planolites*) and calcareous rhizoliths are found within both siltstone and mudstone units. Vertebrate fossils are preserved in pebble lag, sandstone, siltstone, and mudstone facies, with the best preservation occurring in the latter two.

4.2. Interpretations, Unit I

We interpret Unit I as resulting from deposition by fluvial and floodplain processes in a continental rift setting. Paleocurrent measurements suggest that sandstone beds primarily reflect deposition by a northwest-flowing river system oriented parallel to the axis of the basin. The proximity of these rocks to the southern margin of the Rukwa Rift, in conjunction with the coarse, immature nature of the sandstones suggests a proximal source area. Basal pebble lenses are interpreted as channel lag deposits, while the thin, discontinuous mudstones and siltstones represent floodplain deposits. Evidence of rare calcareous rhizoliths and heavy oxidation indicates at least moderate pedogenesis. Abundant erosional scour and truncation of mudstone and sandstone beds demonstrate limited accommodation space during the deposition of Unit I,

and indicate that lateral braid plain migration and cannibalization of floodplain fines was common.

Dypvik et al. (1990) examined the sandstone petrology of the Red Sandstone Group and noted the preponderance of chemically weathered grains; thus, they suggested that these strata were deposited under warm, subtropical conditions in which heavy rains may have been common.

4.3. Observations, Unit II

A second lithologic unit identified in the Songwe Basin, Unit II, is known from limited outcrop areas located south of the Tanzam Highway along the Songwe River (Figs. 3, 4). Unit II is erosionally truncated by overlying Pliocene–Quaternary Lake Beds strata, including conglomerate, siltstone and vitric tuff. It reaches a maximum thickness of 8 m and can be traced laterally for several hundred meters before it is erosionally truncated by overlying beds and/or covered by dense vegetation. In contrast to Unit I, Unit II is significantly lighter in color and dominated by orange-red (10R 6/6), reddish brown (10R 4/6) and grayish pink (10R 8/2) sandstones, mottled red (5R 4/6) and greenish gray (5GY 6/1) mudstone, and purplish red (5RP 2/2) claystone with white (N9) carbonate horizons (Figs. 4, 5). Unit II sandstone beds are typically less well-cemented than those in Unit I, and show both lenticular channel form and sheet architecture. They consist of medium–coarse, poorly–moderately sorted sand in a clay matrix (Fig. 4). Thin, 1–10 cm, pebble lenses are commonly present near the base of sandstone beds. Petrographically, Unit II is compositionally similar to Unit I, being composed of quartz (60%), lithic, igneous and metamorphic rock fragments (25%), and feldspar (15%). Beds range from 0.1–1 m thick, and are typically massive to trough cross-stratified (small-medium scale). Vertebrate and invertebrate fossils, including internal casts of gastropods, crustacean claws, and small, isolated bones and teeth are common in the massive sandstone and mudstone beds near the base of the section (Fig. 4).

Mudstones are more common than in Unit I. They are typically sandy and red colored, with greenish reduction halos, and abundant root mottling and calcareous rhizoconcretions. Slickensides are also present in varying abundance. Distinctive purplish red claystone crops out in the upper half of the section and contains well-developed, white nodular carbonate horizons. Such claystone is unique to Unit II, making this facies a useful criterion for field recognition.

4.4. Interpretations, Unit II

Unit II is also continental in origin. Lenticular sandstone beds are interpreted to represent fluvial

channel deposits, whereas massive, muddy sandstones probably represent higher energy flood deposits. Pebble lenses are interpreted as channel lags, while mudstone, siltstone, and claystone beds are floodplain deposits. The presence of nodular carbonate horizons, calcareous rhizoconcretions, slickensides, deep oxidization, and reduction halos all demonstrate moderate–intense pedogenesis on the floodplain. Based on these pedogenic features, a relatively warm, seasonally arid depositional environment is suggested for Unit II.

4.5. Fauna, taphonomic modes, and age of the Red Sandstone Group in the Songwe Basin

Wescott et al. (1991) and others have reported a paucity of vertebrate fossils in the Red Sandstone Group. In contrast, we recovered a relatively abundant and moderately diverse fossil assemblage from the study area within the Songwe Basin. Twelve fossil-bearing localities were discovered during the 2002 and 2003 field seasons. Of these, 11 sites are located in Unit I, whereas only one site is in Unit II. Preliminary study of fossil material has provided new data on the age of the Red Sandstone Group, definitively demonstrating the presence of two different time-stratigraphic units (Units I and II) in the Songwe Basin (Figs. 2, 3).

4.5.1. Fossils, Unit I

Fossils identified thus far in Unit I comprise a range of isolated to partially articulated specimens, and represent a diverse fauna, including sauropod and theropod dinosaur fossils, (probable) titanosaurid sauropod eggshell, teleost (osteoglossomorph) fish, lungfish, crocodiles, turtles, birds, and mammals (e.g., Krause et al., 2003; O'Connor et al., 2003; Gottfried et al., 2004). Many localities contain isolated remains, particularly within the basal pebble conglomerates of fluvial sandstones. In contrast, other localities preserve associated to partially articulated specimens (e.g., dinosaurs) that demonstrate the in situ nature of fossil material in Unit I. More specifically, one locality contains the associated and partially articulated skeleton of a titanosaurian sauropod within a muddy siltstone (Fig. 5; Unit I measured section ca. 69 m level). This specimen preserves delicate cervical ribs, articulated vertebrae, associated ribs, teeth, portions of the pectoral limb and a variety of other elements that clearly demonstrate the autochthonous nature of the specimen and the low-energy conditions in which it was buried (Fig. 6).

The presence of in situ nonavian dinosaurs allows us to reject a Tertiary age assignment for Unit I. Furthermore, the recovery of osteoglossomorph fish and gondwanatherian mammals suggests a Cretaceous age for this fauna (Krause et al., 2003; O'Connor et al., 2003).

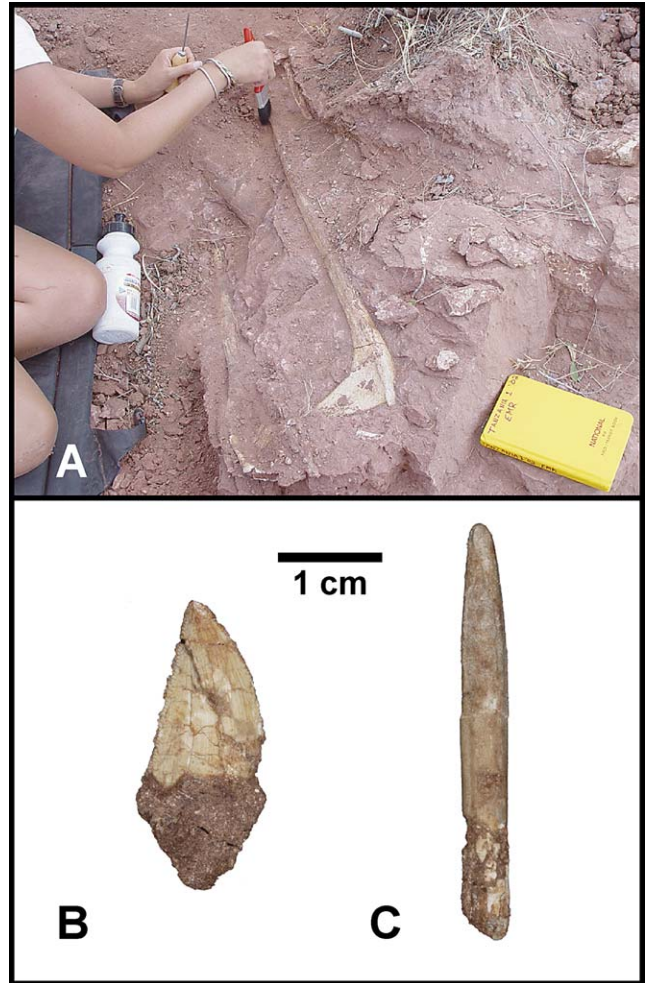


Fig. 6. Examples of dinosaur fossils recovered from the older Unit I of the Red Sandstone Group (TZ-07 Locality). A, dorsal rib (and other bones) of a sauropod dinosaur (NMT02100). B, theropod dinosaur tooth (NMT02088). C, sauropod dinosaur tooth (NMT02093).

4.5.2. Fossils, Unit II

A distinctly different fauna was recovered from Unit II that indicates a much younger age. The one locality identified thus far (TZ-01) preserves a diverse assemblage of gastropods, crustaceans, fish, frogs, crocodiles, birds, and mammals. The locality is dominated by small (<2–3 cm), isolated vertebrate remains, including numerous rodent jaws and teeth, and various frog, rodent and bird limb elements. The majority of fossil material comes from a laterally extensive microsite located in a massive muddy, medium–coarse-grained, tabular sandstone bed that is interpreted either as a channel lag, or more likely, as a flood deposit. Preliminary analysis of the fauna suggests a late Paleogene age for the unit based primarily upon the presence of multiple phiomorph rodent taxa currently under study by one of us (NS). These taxa are narrowly restricted to early Oligocene deposits elsewhere in Africa, such as the upper levels of the Jebel el Qatrani Formation of Egypt

(Schneider, 1984; Kappelman et al., 1992; Holroyd, 1994). Our age assessment is consistent with findings in other parts of the Rukwa and Malawi rift basins that support Tertiary basin development and sedimentation events (e.g., Tiercelin et al., 1988; Wescott et al., 1991; Damblon et al., 1998; van der Beek et al., 1998); however, this is the first reported Paleogene age assignment, supported by faunal evidence, for the Red Sandstone Group.

5. Discussion

The controversy over the age and lack of consistent nomenclature of the Red Sandstone Group demonstrates the complexities encountered when working in continental rift settings. Identification of both Tertiary and Cretaceous units confirms that the Red Sandstone Group was deposited during at least two different depositional episodes, and helps to resolve some of the earlier confusion concerning its age. Structural data (e.g., Ebinger et al., 1989) suggest that the Red Sandstone Group was deposited in a series of highly compartmentalized sub-basins that may well have different depositional histories. Paleontological and stratigraphic data presented here corroborate these structural inferences, even within the relatively geographically restricted Songwe Basin. The relative quality and diversity of fossil preservation within the Songwe Basin and other exposure belts of the Red Sandstone Group holds promise for more fully elucidating the stratigraphic relationships between these different areas. Detailed paleontologic, stratigraphic, and sedimentologic investigation of the Usevia, Rungwe, and Galula areas will be crucial, as these have all provided data (commonly conflicting) regarding the age of the Red Sandstone Group. Moreover, with additional work the nomenclatural ambiguity associated with the Red Sandstone Group may be addressed, particularly with regard to delineating the temporally distinct strata comprising the group.

6. Conclusions

Recent stratigraphic, sedimentologic, and paleontologic investigations of the Red Sandstone Group are beginning to clarify the age and depositional history of strata within the Rukwa Rift Basin. This work demonstrates the presence of two temporally distinct units of the Red Sandstone Group, one Cretaceous in age (Unit I) and one that is Paleogene (Unit II), based upon stratigraphic, paleontologic, and sedimentologic relationships.

Unit I represents a period of late Mesozoic basin development and sedimentation, and preserves a diverse

vertebrate fauna including nonavian dinosaurs, osteoglossomorph fish and gondwanatherian mammals, with the latter two supporting a Cretaceous age. Unit II represents a more recent depositional event, probably Paleogene, on the basis of multiple taxa of rodents belonging to the Phiomorpha. This is the first faunally supported Paleogene age assessment for the Red Sandstone Group.

In addition to improving the stratigraphy and sedimentology of the Red Sandstone Group, this study demonstrates the potential of the Songwe Basin in southwestern Tanzania for preserving both invertebrate and vertebrate fossil remains. The region's central location on the Gondwanan landmass suggests that it can provide critical data for understanding the sequence and timing of events leading up to the separation of the southern continents. Finally, the presence of both Cretaceous and Tertiary fossil-bearing sediments in our field area underscores its importance for addressing a number of paleobiogeographic hypotheses regarding the evolution of vertebrate faunas in Gondwana through time.

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