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Sedimentology and paleoenvironments of a new fossiliferous late Miocene-Pliocene sedimentary succession in the Rukwa Rift Basin, Tanzania

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This paper presents a detailed sedimentologic investigation of a newly identified, fossiliferous Late Neogene sedimentary succession in the Rukwa Rift Basin, southwestern Tanzania. This synrift deposit is a rare and significant new example of a fossiliferous succession of this age in the Western Branch of East Africa Rift System. The unit, informally termed the lower Lake Beds succession, is late Miocene to Pliocene in age based on cross-cutting relationships, preliminary biostratigraphy, and U-Pb geochronology. An angular unconformity separates the lower Lake Beds from underlying Cretaceous and Oligocene strata. Deposition was controlled by rapid generation of accommodation space and increased sediment supply associated with late Cenozoic tectonic reactivation of the Rukwa Rift and synchronous initiation of the Rungwe Volcanic Centre. The lower Lake Beds, which have thus far only been identified in three localities throughout the Rukwa Rift Basin, are characterized by two discrete lithologic members (herein A and B). The lower Member A is a volcanic-rich succession composed mostly of devitrified volcanic tuffs, and volcaniclastic mudstones and sandstones with minor conglomerates. The upper Member B is a siliciclastic-dominated succession of conglomerates, sandstones, mudstones and minor volcanic tuffs.

Detailed facies analysis of the lower Lake Beds reveals various distinctive depositional environments that can be grouped into three categories: 1) alluvial fan; 2) fluvial channel; and 3) flood basin environments, characterized by volcanoclastic-filled lakes and ponds, abandoned channel-fills and pedogenically modified floodplains. Member A represents a shallow lacustrine setting filled by tuffaceous sediments, which grade up into a system of alluvial fans and high-energy, proximal gravel-bed braided rivers. An unconformity marks the contact between the two members. Member B shows an upward transition from a high-energy, gravel-bed braided river system to a sandy braided river system with increasingly abundant floodplain deposits and well-developed paleosols. Vertebrate fossils are sparse in member A, but common in member B, preserved both within pedogenic soil horizons and as isolated elements and microsites within fluvial channel facies associations. Faunal remains include fishes, turtles and crocodylians, along with well-preserved mammal cranial and post-cranial remains. In addition, freshwater gastropod shells are locally present in member A and continental trace fossils, including abundant fossilized termite nests, are present in both members.

1. Introduction

The Cenozoic East African Rift System (EARS) is well-known for its extensive exposures of richly fossiliferous sedimentary deposits

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and rift-related volcanism. The distribution of vertebrate fossils, including hominin remains, is known primarily from sedimentary deposits in the Eastern Branch of the EARS (e.g., the Ethiopian, Kenyan and Gregory rifts; Brown and Feibel, 1986; Dunkleman, 1986; Fleagle et al., 1991; Hautot et al., 2000; Feibel, 2011). The most famous Miocene-Pleistocene fossil sites in the EARS include Olduvai Gorge and Laetoli in northern Tanzania, the Omo-Turkana basin along Ethiopia-Kenya border, in addition to the Middle Awash, Gona, Hadar and Konso areas within the southern Afar depression of northwestern Ethiopia (e.g., Leakey and Leakey, 1964; Bishop, 1978; White and Suwa, 1987; Leakey et al., 1995; Haile-Selassie et al., 2015). The other major locations in Africa where fossil assemblages of this age with abundant vertebrate faunas and early hominin remains have been discovered is in the Cradle of Humankind just outside of Johannesburg, South Africa. Here, fossil cave sites such as Sterkfontein, Swartkrans, Kromdraai, Drimolen, Gondolin, Gladysvale, Malapa and Rising Star have produced a wealth of Plio-Pleistocene fossils (Lockwood and Tobias, 1999; Menter et al., 1999; Susman and de Ruiter, 2004; Pickering et al., 2007; Berger et al., 2010, 2015; Berger, 2012; Herries and Adams, 2013; Dirks et al., 2010, 2015).

The search for fossiliferous strata documenting this important time interval reaches beyond just South Africa and the Eastern Branch of the EARS, as demonstrated by fossil discoveries in the Lake Chad Basin of Central Africa that extend the record of human evolution back to ~7 Ma ago (Brunet et al., 2002, 2005). However, despite decades of paleontologic exploration, only a handful of fossiliferous Miocene-Pleistocene sedimentary deposits have been documented from the Western Branch (Albertine Rift) of the EARS (Pickford et al., 1993; Bromage et al., 1995a,b; Crevecoeur et al., 2014). These rare Western Branch sites are largely limited to the northern part of the rift branch between Lake Albert and Lake Edward, where lower Miocene to Pleistocene deposits have been described from both the DRC and Uganda. In particular, the Semliki Valley to the south of Lake Albert in Uganda (Pickford et al., 1993), and Ishango on the north side of Lake Edwards (Crevecoeur et al., 2014), have both produced abundant faunal remains which together form part of a fairly extensive succession of fossiliferous lower Miocene-Pleistocene fluvio-lacustrine strata in this region (Roller et al., 2010). To date, the only significant fossil locality of this age in the southern portion of the EARS is in the northern Malawi Rift Basin, a segment of the Western Branch of the East African Rift System (Betzler and Ring, 1995; Roller et al., 2010). The Uraha, Mwenirondo, Malema and Mwimbi sites on the northwestern shores of Lake Malawi preserve a number of relatively isolated, fossiliferous, fluvio-lacustrine, Plio-Pleistocene deposits defined as the Chiwondo beds, which have produced abundant faunal remains, along with a single hominin dentary and other isolated jaw fragments (Clark et al., 1970; Bromage et al., 1985, 1995a, b; Rozzi et al., 1997; Sandrock et al., 2007; Kullmer et al., 2011; Stewart and Murray, 2013).

The late Cenozoic, between 10 Ma and Recent, represents a critical time period in African history, characterized by major environmental and climatic changes associated with the development of the East African Rift System and uplift of southern and eastern Africa (Potts, 1998; deMenocal, 2004; Sepulchre et al., 2006; Maslin and Christensen, 2007; Trauth et al., 2007). It has been suggested that tectonic rifting has played an important role in faunal evolution in Africa, particularly by creating diverse landscapes with dispersal corridors and settings conducive to the development of major river systems and lakes where a mosaic of African species are thought to have lived and evolved (Brown, 1981; Feibel et al., 1991; Potts, 1998; Ashley, 2000; Trauth et al., 2007). Additionally, tectonic rifting is associated with volcanism and high subsidence rates that provide excellent conditions for the production and deposition of sediments, and hence rapid burial of floral and faunal remains (WoldeGabriel et al., 2000; Stollhofen et al., 2008). Rift basins are therefore, important archives of high-resolution tectonic, climatic and environmental data.

Nowhere has the importance of such changes in Africa been of more interest than in the study of the East African Rift System, which has long focused on the interplay between tectonic, environmental and climatic changes for understanding the evolutionary and ecological patterns and distribution of flora and fauna on the continent since the late Miocene (e.g., Vrba, 1988; deMenocal, 1995; Stanley, 1995; Potts, 1998; Kingston, 2007; Maslin and Christensen, 2007; Trauth et al., 2007; Maslin et al., 2014). A key aspect of expanding our understanding of the evolution of East African landscapes and ecosystems depends upon recognition and discovery of new outcrop exposures, particularly in previously under-studied or unknown basins. Whereas late Neogene deposits in the Eastern Branch of the East African Rift System have been extensively explored and studied, many parts of the Western Branch of the EARS have yet to be extensively explored and documented. In this paper, we document a vertebrate, invertebrate and trace fossil-bearing late Neogene stratigraphic succession in the Rukwa Rift Basin of southwestern Tanzania, informally referred to here as the lower Lake Beds succession. This study was conducted as part of the Rukwa Rift Basin Project (see Roberts et al., 2004, 2010, 2012; O'Connor et al., 2006, 2010; Stevens et al., 2008, 2013), which is focused on the discovery and documentation of the palaeontologic history of the rift over the last 100 million years in combination with refining the tectonic and sedimentary history of the basin. The purpose of this paper is to describe the distribution and detailed sedimentology of the lower Lake Beds Succession and to provide a preliminary stratigraphic and paleoenvironmental context for this newly recognized Neogene vertebrate fossil locality in East Africa.

2. Regional geology and background

The northwest-trending Rukwa Rift Basin (RRB) is part of the Western Branch of the East African Rift System, situated between the Tanganyika and Malawi rifts in southwestern Tanzania (Fig. 1). The basin is about 360 km long and 40 km wide, bounded to the northeast by the linear Lupa border fault and Tanzania Craton, to the southwest by the Ufipa fault and uplifted Ufipa block, and to the south and southwest by the Rungwe volcanics and Mbozi block, respectively (Ebinger et al., 1989; Kilembe and Rosendahl, 1992). The RRB has a half-graben architecture, and is flanked by uplifted Paleoproterozoic metamorphic basement rocks of the Ubendian shear belt (Quennell et al., 1956; Daly et al., 1985; Lawley et al., 2013).

The Rukwa Rift was initiated during the Paleozoic by reactivation of Paleoproterozoic to Neoproterozoic sinistral shear zones in the NW-SE trending Ubendian Belt (Theunissen et al., 1996). Structural development of the RRB has provoked debate among researchers. The RRB was first proposed to have formed as a strike-slip pull-apart basin in an oblique, northwest-southeast extensional setting based on interpretations of linear map geometry and oblique orientation to the general north-south trend of EARS, as well as from satellite images and seismic profiles (Chorowicz and Mukonki, 1980; Kazmin, 1980; Tiercelin et al., 1988). The oblique opening model was later supported by outcrop-based structural studies that indicated dominantly low angle, dextral kinematics along the Lupa Fault (Wheeler and Karson, 1994). However the basin geometry and listric fault shape observed in seismic reflection data does not fit a pull-apart basin, and other workers have suggested east-west to northeast-southwest extension, and oblique opening of an extensional rift basin, influenced by northwest-