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History of the development of the East African Rift System: A series of interpreted maps through time

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A R T I C L E I N F O

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A B S T R A C T

This review paper presents a series of time reconstruction maps of the 'East African Rift System' ('EARS'), illustrating the progressive development of fault trends, subsidence, volcanism and topography. These maps build on previous basin specific interpretations and integrate released data from recent petroleum drilling. N–S trending EARS rifting commenced in the petroliferous South Lokichar Basin of northern Kenya in the Late Eocene to Oligocene, though there seem to be few further deep rifts of this age other than those immediately adjoining it. At various times during the Mid-Late Miocene, a series of small rifts and depressions formed between Ethiopia and Malawi, heralding the main regional rift subsidence phase and further rift propagation in the Plio-Pleistocene. A wide variation is thus seen in the ages of initiation of EARS basins, though the majority of fault activity, structural growth, subsidence, and associated uplift of East Africa seem to have occurred in the last 5–9 Ma, and particularly in the last 1–2 Ma. These perceptions are key to our understanding of the influence of the diverse tectonic histories on the petroleum prospectivity of undrilled basins.

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1. Introduction

The East African Rift System ('EARS') represents the world's best example of an active rift system, although its deep origins remain poorly understood. The objective of this review paper is therefore to integrate the voluminous literature on the EARS with partially released subsurface well data, in order to compile a series of maps showing the progressive development of the system through time. These maps will remain dynamic as more data is released on drilling in the region and further studies are undertaken.

There is widespread confusion in the application of the term 'East African Rift System' ('EARS'). Multiple ages of rifting in East

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Africa are recognised (Fig. 1), including extensive systems of Permo-Triassic and Cretaceous age, in each case themselves consisting of several stacked rift phases (Kreuser, 1995). The term 'East African Rift System' ('EARS') tends to be applied only to rifts of Cenozoic age (e.g. Chorowitz, 2005), but even here there may be confusion, as there are three overlapping subsets of Cenozoic rifts (Figs. 1 and 2), namely (a) those of Early Paleogene age, which usually represent a continuation of rifting from the Late Cretaceous (e.g. Anza Graben, (Morley et al., 1999c)), (b) those of ?Eo-Oligocene to Early Miocene age, and (c) the currently active set of rifts, dating, according to this work, back to the Mid Miocene. This paper is confined to the study of the two youngest of these phases, i.e. those which are not continuations of the NW–SE Cretaceous rifts, though it is realised that some of the EARS rifts may be reactivations of earlier rifts (e.g. Rukwa Basin, Fig. 2). The EARS rifts show a general N–S trend, except over the long-lived Ubendian line of basement weakness through the Rukwa Basin (Klerkx et al., 1998), where they swing to follow NW–SE basement trends (Figs. 1 and 2, Delvaux, 2001). The limited number of rifts active from? Eo-Oligocene through to the Early-Mid Miocene boundary, of which the type example is the South Lokichar Basin (Morley et al., 1999b), are referred to in this paper loosely as 'EARS 1' rifts, while the more extensive Late Neogene (Mid Miocene to Recent) rifts, typified by the Albertine Basin (Pickford and Senut, 1994), are referred to as 'EARS 2' rifts. In most cases, in the onshore, these two phases seem to be geographically distinct, as is illustrated on Fig. 1, and the distinction has been historically emphasised in northern Kenya, where Vetel (1995) and Morley et al. (1999b) document a major shift eastwards through time in the location of rifts. The Mid Miocene division between the two phases also seems to mark the onset of Neogene rifting in the Western Branch, within the Semliki extension of the Albertine Basin (see below), although determining whether this initiation is truly synchronous with the rifting shift in the Turkana Area needs better biostratigraphic control than is available at present. This division is therefore useful for descriptive purposes, but is likely to be refined in the future as more precise dating becomes available. Offshore rifts active during this timescale are also presented and discussed in this paper, though these are of doubtful direct affinity to the onshore rift systems and less easily follow the EARS 1/EARS 2 division. Essentially, therefore, this is a paper which assimilates our current state of knowledge on Oligocene-Recent rift activity in East Africa. The names applied for each of the basins described are shown in Fig. 2.

Data and interpretations assimilate previous regional and semi-regional evaluations of the EARS (e.g. Chorowitz, 2005; Morley et al., 1999a), published outcrop-based studies, particularly of volcanic dating and geometries related to faulting (e.g. Wichura et al., 2011) and lakebed lithological studies (e.g. Tiercelin et al., 1992). Geophysical contributions include gravity modelling to identify deep rifts (e.g. Ebinger et al., 1989), published subsurface seismic studies (e.g. Scholz/Project Probe, 1989) and new seismic mapping by the author of the PROBE seismic over Lake Tanganyika, Lake Malawi (including Surestream Petroleum reprocessed data) and Lake Turkana. Public domain seismic data and mapping by other authors have also been incorporated from various sources over the Lake Albert, Rukwa, South Lokichar, Turkana, Omo, Chew Bahir, Anza and Kerio basins (as listed in Table 1).

Available well information, with the fullest datasets from pre-2005 wells, is shown in Table 1. There has been a recent spate of drilling of Ugandan, Ethiopian and Kenyan EARS basins, though only sparse data is available on post-2005 wells through

Table 1
Published well and seismic data, plus source of mapped faults, over the East African Rift System.

Well	Basin	Reference	Key points
Kingfisher 1,2,3	Albertine	Logan et al. (2009)	Thick Plio-Pleist. Late Miocene over Basement. Tie to seismic. Published biostrat
Turaco wells	Albertine/Semliki	Abeinomugisha and Kasande (2012), Lukaye (2009)	1400 m thick Mid-Late (and ? Early) Miocene section
Ngassa 2	Albertine	Sserubiri and Scholz (2012)	Early Pliocene source rocks described at 3000–3250 m close to Basement surface
Waki 1	Albertine	Karp et al. (2012)	Undated section with source rocks over Basement
Nyuni 1	Lake Edward	Dominion (2011)	Late Pliocene over Basement
Ruzizi 1	Ruzizi	Morley and Wescott (1999)	Undated section
Buringa 1	Ruzizi	Morley and Wescott (1999)	Undated section
Ivuna 1	Rukwa	Morley et al. (1999d)	Latest Miocene-Pliocene over top Oligocene unconformity
Galela 1	Rukwa	Morley et al. (1999d)	As above
Syracuse Borehole A	Lake Malawi	Scholz et al. (2011), Lyons et al. (2011)	TD at 390 m at date of 1.2 Ma
Loperot 1	South Lokichar	Talbot et al. (2004), Morley et al. (1999b)	Early Miocene reservoirs and source rocks, Eo-Early Olig close to mapped Basement
Eliye Springs 1	Turkana	Morley et al. (1999b)	Tie for thick Plio-Pleistocene and thinner ?Late Mio section in Turkana rift
Ngamia 1	South Lokichar	Africa Oil (2013)	Early Miocene reservoirs and source rocks
Twiga 1	South Lokichar	Africa Oil (2013)	As above
Seismic programme	**Basin**	**Reference**	**Mapping of faults in this paper by**
Project PROBE	Lake Tanganyika	Rosendhal (1988)	Author
Project PROBE	Lake Malawi	Scholz/Project Probe (1989)	Author
Project PROBE	Lake Turkana	Dunkelman et al. (1989)	Author
Amoco Seismic Rukwa Basin	Rukwa	Morley et al. (1999d)	Morley et al. (1999d)
Amoco Seismic South Lokichar, Kerio and Turkana Basins	South Lokichar	Morley et al. (1999b)	Morley et al. (1999b)
Early Academic Seismic Lines	Albertine	Karp et al. (2012)	Karp et al. (2012), Abeinomugisha and Kasande (2012)
Recent Commercial Seismic Lines	South Omo, Chew Bahir, Ethiopia: Turkana and South Kerio, Kenya	Africa Oil (2013)	Africa Oil (2013)