wjert, 2022, Vol. 8, Issue 1, 01-23. **Review Article** **ISSN 2454-695X**

World Journal of Engineering Research and Technology

WJERT

www.wjert.org **Impact Factor Value: 5.924**

ORIGIN, STRUCTURE AND ASSOCIATED MINERAL RESOURCES OF EAST AFRICAN RIFT SYSTEM: AN OVERVIEW

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Article Received on 23/10/2021 **Article Revised on 13/11/2021** **Article Accepted on 03/12/2021**

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ABSTRACT

The East African Rift System is one of the most outstanding and significant rift systems on earth and transects the high-elevations of Ethiopian and East African Plateau. The present paper is an overview of the origin, structure and associated mineral resources of the rift system. It extends from the Red Sea/Gulf of Aden to Malawi and it is seismically active. The rift started in the north in early Tertiary and propagated south with time. The EAR began developing around the onset of the Miocene, 22–25 million years ago. It is developed on crust that exhibits a relatively simple Phanerozoic history of successive rift and sag basins formed during the Paleozoic, Mesozoic, and early Tertiary. The East African rift system can be regarded as a unique succession of graben basins linked by intracontinental transforms and segmented by transfer zones and accommodation zones. The major countries in the area include: Tanzania Kenya, Uganda, Ethiopia, Somalia, Mozambique, Burundi and Rwanda. The rift system covers an area of about 8,000,000.00km^2. With respect to mineral resources, gold, hematite, diamond, nickel, limestone, coal and natural gas occur extensively area. Moreover, the East African Rift System is a complicated system of rift segments which provide a modern analog to help us understand how continents break apart. It is also a great example of how many natural systems can be intertwined - this unique geological setting may have altered the local climate which may have in turn caused our ancestors to develop the skills necessary to walk upright, develop culture and ponder how such a rift came to be.

KEYWORDS: East African, Rift system, Tertiary, mineral resources, Kenya, Tanzania and Ethiopia.

1.0 INTRODUCTION

The concept of 'East African rift fracture' was established by Suess (1891), following the explorations and discoveries of Livingstone, Stanley, Fischer, Thomson, Teleki and Von Höhnels during the XIXth century. Gregory in 1896 named it the 'Great Rift Valley of East Africa', and in 1921 he described a system of graben basins including the Red Sea and Dead

Sea systems, forming the Afro-Arabian rift system (Chorowicz, 2005).

The East African rift system is widely recognized as the classical example of a continental rift system which is part of the Afro Arabian rift system that extends from the Red Sea to Mozambique in the south. As the rift extends from the Ethiopian segment southwards it bifurcates at about (5^oN) into the Eastern and Western branches. The two branches of the rift skirts around the Tanzania craton and formed within the Late Proterozoic belts adjacent to the margins of the craton (Mosley, 1993; Smith and Mosley, 1993; Omenda, 2007). However, the Eastern Branch that comprises the Ethiopian and Kenya rifts is older and relatively more volcanically active than the western branch that comprises Albert–Tanganyika-Rukwa-Malawi rifts (Omenda, 2007).

The East African Rift System is one of the most outstanding and significant rift systems on earth and transects the high-elevation Ethiopian and East African Plateau. The East African Rift system extends from the Red Sea/Gulf of Aden to Malawi and it is seismically active beyond. The rift started in the north in early Tertiary and propagated south with time.

This paper is focused on an overview of the origin, structure and associated mineral resources within the east African rift system.

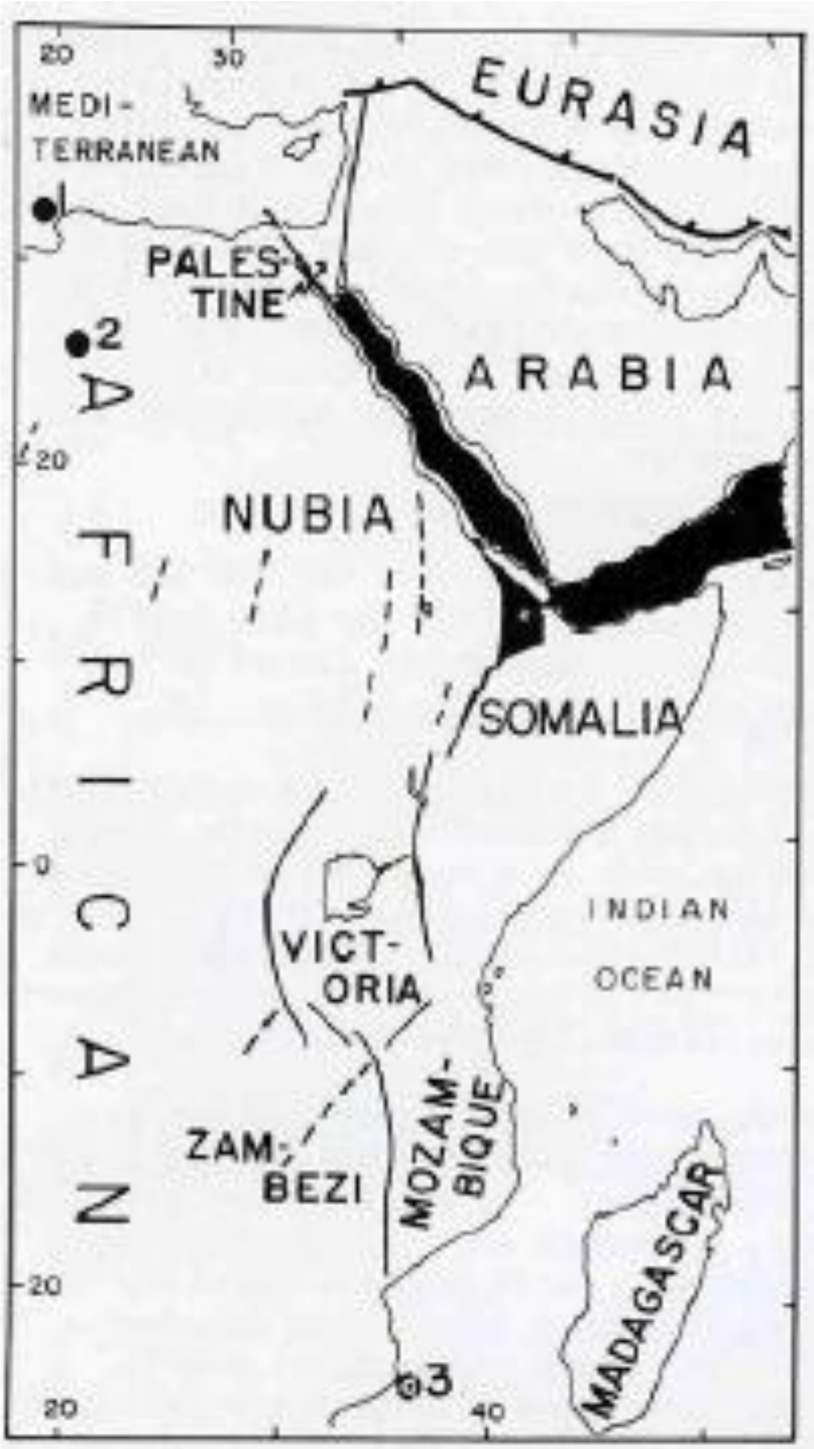

Figure 1: Plate tectonics of the Afro-Arabian rift system. Black areas marked neooceanic crust formed by spreading within this system. Solid lines mark plate boundaries; dashed lines mark intraplate zones of deformation. (From Baker et al., 1972; Saemundsson, 2010).

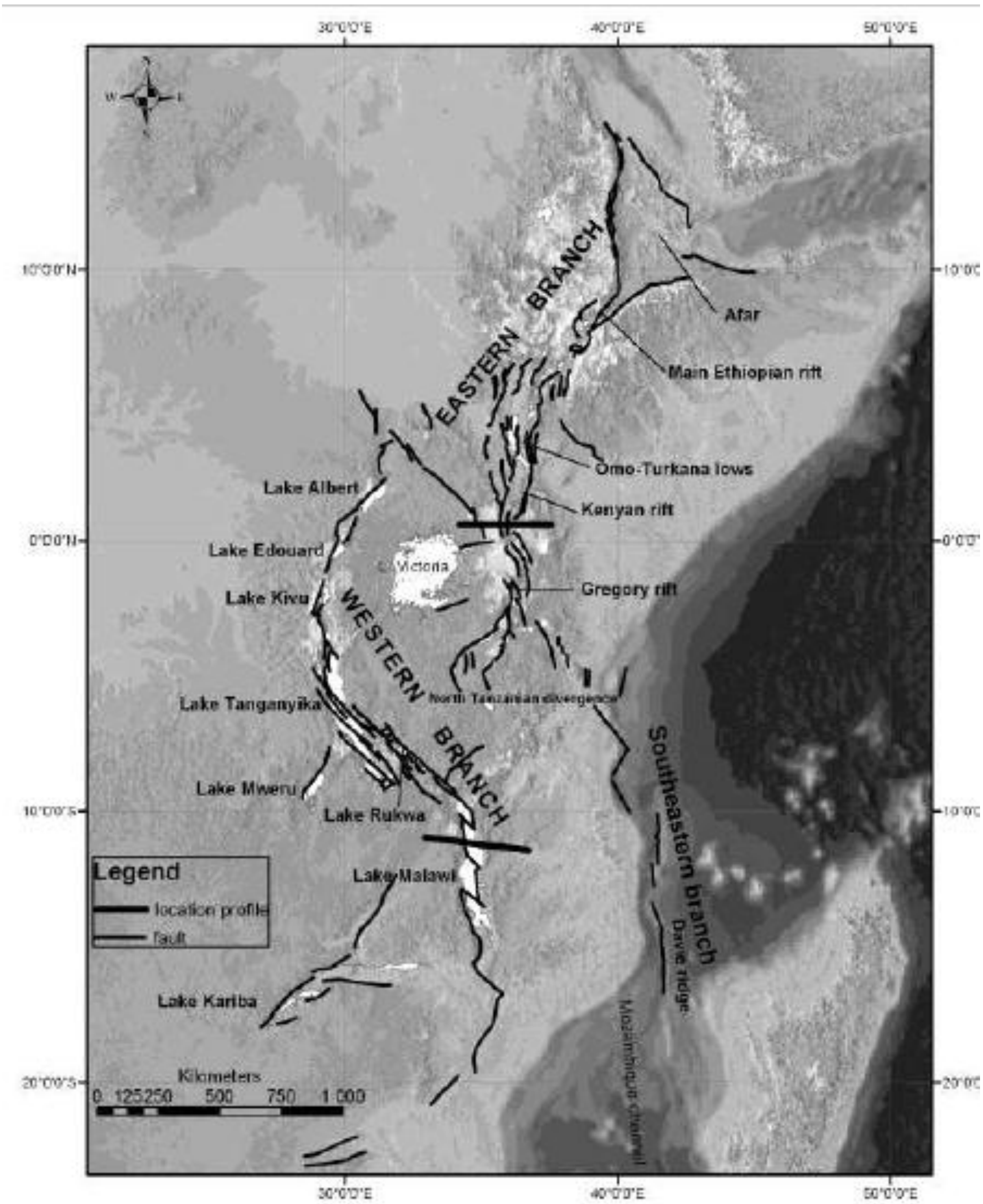

Figure 2: Hypsographic DEM of the East African rift system. Black lines: main faults; E-W dotted lines: locations of cross-sections; white surfaces: lakes; grey levels from dark (low elevations) to light (high elevations) (From Chorowicz, 2005).

2.0 ORIGIN OF EAST AFRICAN RIFT SYSTEM

2.1 Highlights

The East African Rift (EAR) is an active continental rift zone in East Africa. The EAR began developing around the onset of the Miocene, 22–25 million years ago (Ebinger, 2005). In the past, it was considered to be part of a larger Great Rift Valley that extended north to Asia Minor. The rift is a narrow zone that is a developing divergent tectonic plate boundary, where the African Plate is in the process of splitting into two tectonic plates, called the Somali Plate and the Nubian Plate, at a rate of 6–7 mm (0.24–0.28 in) annually (Fernandes et al., 2004).

As extension continues, lithospheric rupture will occur within 10 million years, the Somali plate will break off, and a new ocean basin will form.

Africa has been a center of continental accretion in the Precambrian and Cambrian (Shackleton, 1986; Dixon and Golombek, 1988; Ring et al., 2002; Fritz et al., 2013; Ring, 2014). Today it is surrounded on three sides by divergent plate boundaries.

The East African Rift System comprises several discrete and diachronous rift sectors. Traditionally an Eastern (including the Ethiopian Rift) and a Western Branch are being distinguished (Ring, 2014). Field data have shown that the present trace of the Eastern and Western Branches of the East Africa Rift System largely reflect earlier sutures (Ring, 1994; Burke, 1996; Ring, 2014). Tomographic sections support this view and show that the deep roots of the cratonic blocks play a major role in guiding the upwelling hot mantle emanating from the top of the African Superswell in the upper few hundred kilometers of the mantle (Ebinger and Sleep, 1998; Sleep et al., 2002; Ring, 2014). The earliest basaltic volcanism in the East African Rift System commenced between 45-39 Ma in southwest Ethiopia and northernmost Kenya (Morley et al., 1992; Ebinger et al., 1993; Ring, 2014). During this time period kimberlites were emplaced in Archean cratons surrounding the rift (Harrison et al., 2001; Batumike et al., 2007; Roberts et al., 2012: Ring, 2014).

In the north it has its origin in the Afar hot spot/mantle plume as a huge domal uplift (Afro-Arabian Dome) over 1000 km wide where the oceanic rift soft the Red Sea and the Indian Ocean Ridge meet (Saemundsson, 2010). The East African Rift System forms the third arm, a complex feature with two main rift branches, the Western and the Eastern Rifts. The Eastern Rift of many volcanoes from Suswa up to Turkana is centered on a second hot spot represented by the Kenya domal uplift, which is elliptical in plan and about 1000km wide(Saemundsson, 2010). It has also three rift arms, two of them forming the main rift, the third (Kavirondo) subdued trending west from the centre of the dome. To the north in the Lake Turkana area sedimentation outweighs volcanic production. Prospecting for oil and gas in the sedimentary fill of the basin is being undertaken there. The Western Rift of deep lakes and few volcanoes bends about the eastern edge of the Kenya dome from Uganda to Tanzania continuing south to Malawi. The floor of that rift is filled with sediments (which contain hydrocarbons) and lakes, elongate in shape, occupying depressions up to 4.5 km deep (Tanganyika, lake depth over1400m) but volcanism is subordinate although hosting Africa’s most active volcano in the Virunga mountains (Saemundsson, 2010).

2.2 Geology and Geophysics

There is a close association between doming, rifting and alkaline magmatism/volcanism. The development sees four magmatic episodes correlating with tectonic phases beginning in the Miocene. The first appearance of the development phases are as follows according to Saemundsson (2010):

1. Early to middle Miocene. Early uplift. Alkali basalts, nephelinites.
2. Upper Miocene. Doming of about 300 m. Downwarping at future rift shoulders. Fissure eruptions. More basalts and phonolites. Off rift volcanoes of eastern Uganda.
3. Pliocene. Doming of about 1400 m. Main rifting. Graben faulting. Trachytes in rift floor (Southern Kenya Rift). Basaltic volcanism.
4. Quaternary. Major graben faulting, caldera volcanoes in axial zone Basalt phonolite volcanism in off-rift volcanoes beginning in Upper Pliocene.

2.2.1 Seismic data Geophysical data support the concept that a diapir of relatively low density material is situated below parts of the rift system. A combination of seismic refraction and gravimetric data suggest the presence below the Kenya rift of a low density body of 3.15 g/cm^3 (relative to 3.35 g/cm^3 for cold lithosphere) and P wave velocity of 7.5 km/s from 20 to 60 km depth. It has a lateral extent of 200-250 km wide. This is consistent with seismic results indicating that the crust below the rift is thinned to 20 km (from a normal 36 km for surrounding East Africa) and has an anomalously low sub-Moho velocity (Kahn, 1975; Saemundsson, 2010).

2.2.2 Seismic Survey Suggest that the East African rift system is a zone of shallow earthquakes (average focal depth 20 km) (Saemundsson, 2010). The epicentres are shallowest in Afar, deepest in the southern part of the rift system. Focal mechanism studies show dominantly normal faulting (Kebede and Kulhanek 1991; Stamps et al., 2008). The Western Rift is more active seismically than the Eastern Rift where they run parallel. In the Eastern Rift seismic activity seems to be more concentrated in swarms of certain areas (Saemundsson, 2010).

2.2.3 Gravity surveys of the East African rifts show a progressive change from north to south in accordance with crustal separation and magmatic intensity (Saemundsson, 2010). In the Red Sea where crustal separation is significant and dense material has intruded upwards the gravity (Bouguer) anomalies are highest (Saemundsson, 2010). Ethiopia also has a positive gravity anomaly but in Kenya there is a narrow positive within a broader (350 km) negative anomaly (-50 mgal). To the south of Kenya there is only a negative anomaly which decreases in amplitude southwards, eventually disappearing in North-Tanzania (Saemundsson, 2010).

2.2.4 Magnetic surveys are the main method to trace the history of the ocean floor. Thus the age and spreading rates of the Red Sea and Gulf of Aden have been revealed. The method is less effective in the East African Rift, but yet it may serve to define the extent of a volcanic pile of rocks as against a predominantly sedimentary succession (Saemundsson,, 2010). In geothermal prospecting it is helpful in outlining areas of altered rocks as the magnetite in them is destroyed.

2.2.5 Resistivity surveys are a powerful tool in geothermal prospecting. This also applies to *magnetotellurics*, which is also important in probing below the 800-1000 m depth limit of conventional resistivity methods (Schlumberger or TEM) in the study of Saemundsson (2010).

3.0 STRUCTURE OF EAST AFRICAN RIFT SYSTEM

3.1 Pre-Rift Structure

The East African Rift System is developed on crust that exhibits a relatively simple Phanerozoic history of successive rift and sag basins formed during the Paleozoic, Mesozoic, and early Tertiary (Morley et al., 1999). Most important in terms of extent and influence on the EARS geometry is the Precambrian crystalline basement. The basement is formed by a number of relatively stable Archean cratonic areas surrounded by orogenic sutures (orogenic or mobile belts). The good quality of exposures associated with the East African Rift, aided by the absence of a thermal sag basin, enables the interaction between rift structure and basement fabric to be investigated (Morley et al., 1999). The region serves as a good analog for the role of fabrics on rift structure.

3.2 Extent and Overall morphology

3.2.1 Highlights

East African rift system (EARS) is a succession of rift valleys that extend from Beira in Mozambique in the south to Afar triangle in the north; a total distance of more than 4,000-km (Omenda, 2007). The EARS is a continental branch of the worldwide mid ocean rift system that corresponds to the third arm of the Afar- Red Sea – Gulf of Aden triple junction (Omenda, 2007). The rift is assumed to mark the incipient plate boundary between the Somali and Nubian micro-plates and linked to the Afar- Red Sea – Gulf of Aden rift systems (Figure 2). The EARS splits into two at about 5^{o}N to form the Eastern and Western branches. A third, southeastern branch is in the Mozambique Channel. The eastern branch runs over a distance of 2200 km, from the Afar triangle in the north, through the Main Ethiopian rift, the Omo-Turkana lows, the Kenyan (Gregory) rifts, and ends in the basins of the North- Tanzanian divergence in the south (Chorowicz, 2005). The western branch runs over a distance of 2100 km from Lake Albert (Mobutu) in the north, to Lake Malawi (Nyasa) in the south (Chorowicz, 2005). The Eastern branch comprises the Afar, Ethiopian, Turkana and Kenya Rifts while the western branch comprises Albert, Kivu, Tanganyika, Rukwa and Malawi Rifts. The SW branch comprises Luangwa-Kariba-Okavango rifts (Omenda, 2007). It comprises several segments: - the northern segment includes Lake Albert (Mobutu), Lake Edward (Idi Amin) and Lake Kivu basins, turning progressively in trend from NNE to N-S; - the central segment trends NW-SE and includes the basins of lakes Tanganyika and Rukwa; - the southern segment mainly corresponds to Lake Malawi (Nyasa) and small basins more to the south (Chorowicz, 2005). The south-eastern branch comprises N-striking undersea basins located west of the Davie ridge. Most of the great lakes of Eastern Africa are located in the rift valleys, except notably Lake Victoria whose waters are maintained in a relative low area between the high mountains belonging to the eastern and western branches (Chorowicz, 2005).

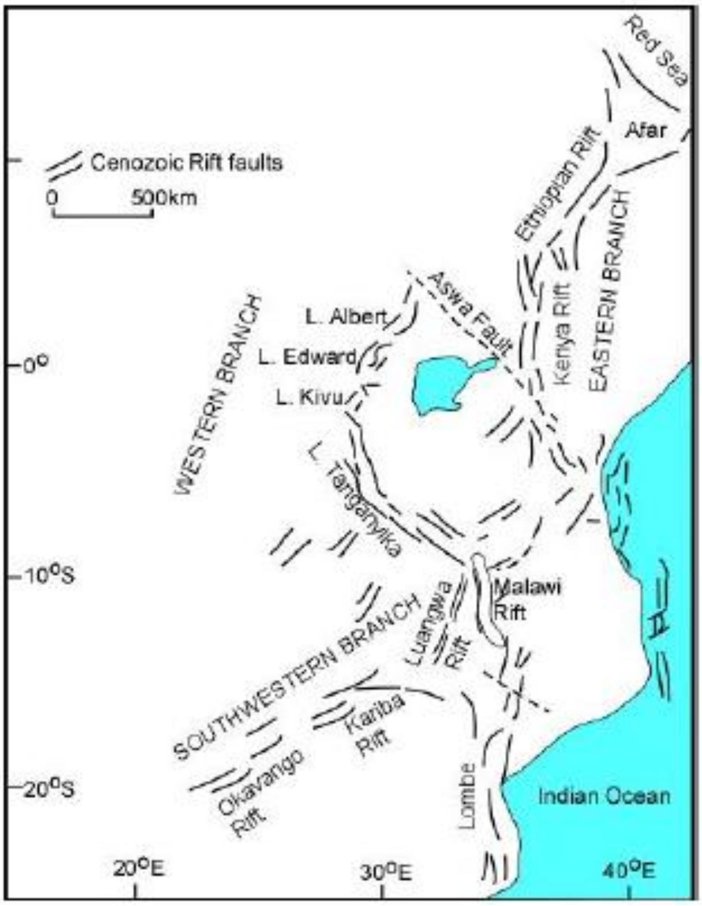

Figure 3: Structural map showing the East African Rift System (Adapted from Atekwana et al., 2004; Omenda, 2007).

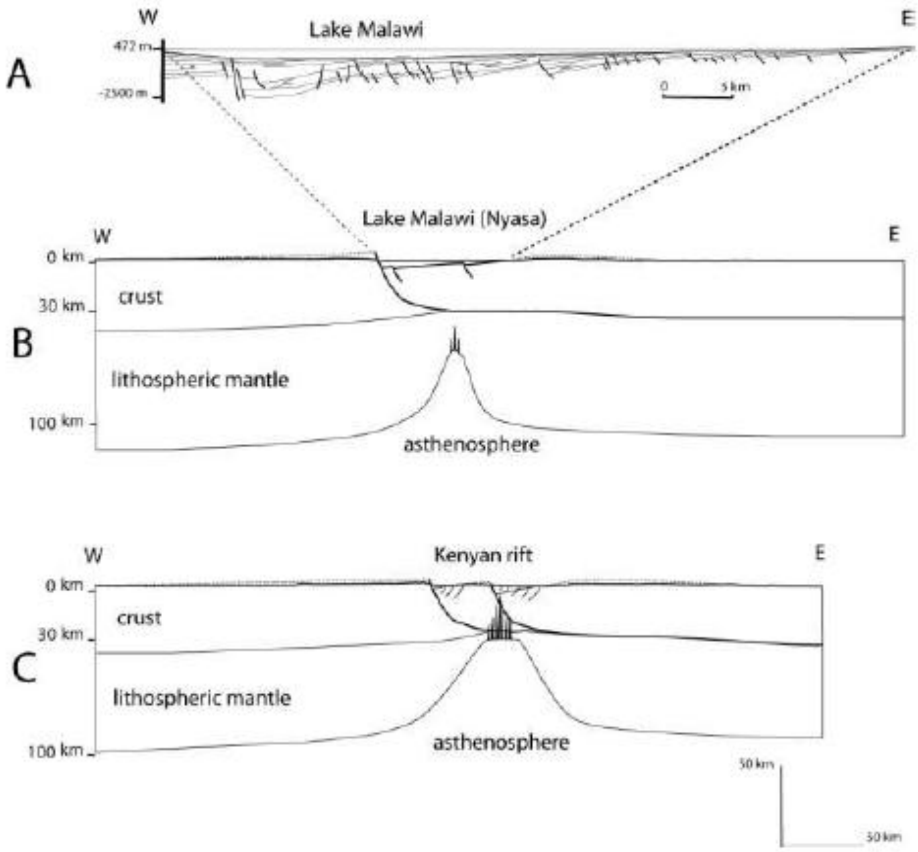

Figure 4: Representative lithospheric profiles of the EARS. Vertical lines are inferred dyke intrusions. Dotted lines show the envelope surface before erosion. A. Seismic reflection profile of Lake Malawi (Rosendahl et al., 1992). B. Inferred lithospheric cross-section of Lake Malawi. C. Inferred lithospheric cross-section of the northern Kenyan rift (From Chorowicz, 2005).

3.2.2 Main tectonic features

According to Chorowicz (2005), the morphotectonics of the EARS are under control of divergent movements, vinducing localized extensional strain in the continental lithosphere. The brittle crust has reacted by faulting and subsidence, forming elongate, narrow rifts, while the lithospheric mantle is subjected to sharply define ductile thinning, inducing ascension of asthenospheric mantle.

The most characteristic features in the rift system are then these narrow elongate zones of thinned lithosphere related to deep intrusions of asthenosphere in the upper mantle. This hidden part of the rift structure is expressed on the surface by thermal uplift of shoulders, and argued by geophysical data (Chorowicz, 2005).

On the surface, the main tectonic features are normal faults, but there are strike-slip, oblique-slip and sometimes reverse faults. Extension produces widespread open fractures, comprising tension gashes. Most of the fractures are syn-depositional, and when volcanism occurs, it is closely related to the tectonics. Major fault characteristics are shown by an example, the 'split crater' (Jutz and Chorowicz, 1993), located in Kenya.

3.2.3 Tectonics and sedimentation

The sedimentation patterns in the EAR system are controlled by structures, with strong influence of climatic environments and occurrence of great lakes (Frostick and Reid, 1990; Lambiase and Bosworth, 1995; Chorowicz, 2005). In the vicinity of the graben basins, preexisting structures and recent faults focus drainage and input place of sediments, while regional uplift of rift shoulders induces high energy erosion, but part of the drainage is deflected away from rift.

Detritic sediments accumulate at piedmont of major border faults, forming alluvial cones, alluvial and delta systems, down slope fan deltas and deep fan deltas (Chorowicz, 2005). There is sometimes development of littoral platforms with fan deltas, prograding deltas, underflows from canyons, carbonate deposits, stromatolites. The platforms and monocline tilted blocks are dissected by gorges. Landslides, rock fall deposits and deep fans are located at foot of the major boundary faults. In axial deep basins there are "sheet drape" sequences of homogeneous or laminated organic-rich mud, in anoxic conditions, and distal turbiditic sedimentation (Chorowicz, 2005). The predominance of rift parallel fault blocks facilitates axial sediment transport, at the expense of down-dip, lateral transport. The transfer and transform faults separate several depocentres, which asymmetry is related with the roll-over patterns (Chorowicz, 2005). Organic sediments are preserved in deep and sometimes shallow basins. Evaporitic sediments are under semi-arid climate, in shallow basins. Metallogenic deposits are related to hydrothermalism along major border faults (Tiercelin et al., 1992; Thouin and Chorowicz, 1993; Chorowicz, 2005).

3.2.4 Volcanism

Cenozoic volcanism in the EARS is widespread in the north – especially eastern branch-, but sparse in the south. In other rift systems of similar length, such as the West European rift, volcanism is much scarcer. Abundant volcanism in Northeast Africa is related to plume occurrence (Schilling, 1973; Schilling et al., 1992; Keller et al., 1994). The scenario of north to south migration of plume activity (Bonavia et al., 1995) is consistent with the thin lithosphere shown by a large N-S trending gravimetric negative Bouguer anomaly in eastern-central Africa (Wohlenberg, 1975; Girdler, 1978; Simiyu and Keller, 1997), and explains the differences in volcanism between western and eastern rifts, and north or south.

The magmas are alkaline to hyperalkaline, and typically evolved from continental tholeiites rich in incompatible elements, through alkalic products to transitional magmas relatively low in incompatible elements (Mohr et al., 1972). There is a predominantly alkali basaltic source with contributions from a lower crustal protolith (Hay et al., 1995). According to Macdonald (1994), all major sequences show evidence of extensive polybaric fractionation within the upper mantle and lower crust. Inter-crustal fractionation has commonly been accompanied by assimilation and the development of silica-(sometimes over-)saturated liquids.

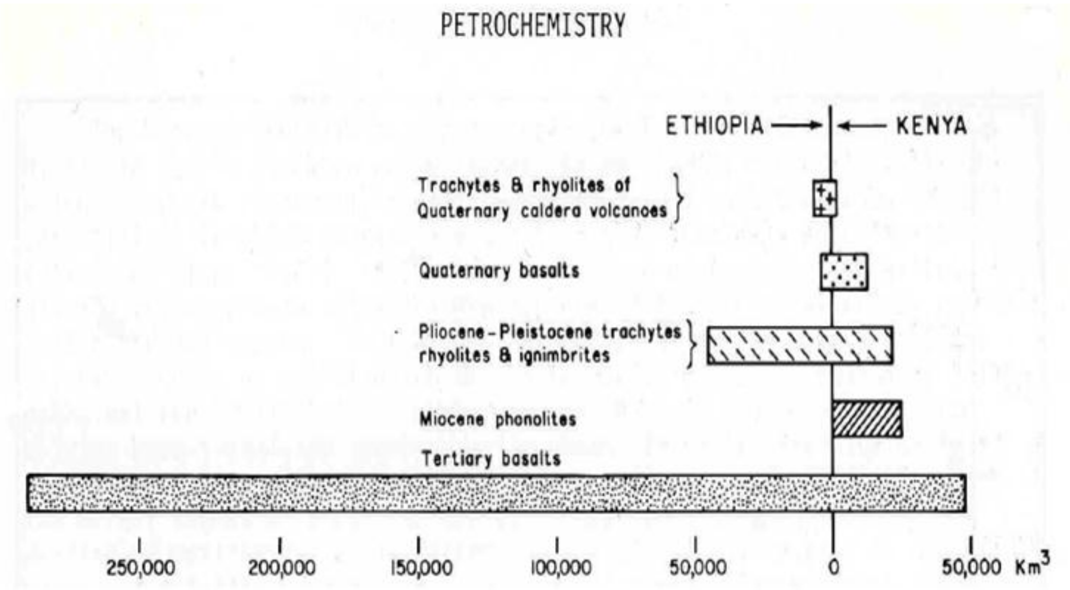

Figure 5: Estimated volumes of eastern rift volcanic (From Baker et al., 1972).

3.3 Precambrian Basement

Of the five Archean cratons that make up southern Africa, two play an important part in the EARS, these are the Zambian and Tanzanian Cratons. Both are composed of para- and orthogneisses, with associated basic and ultrabasic rocks (Anhaeusser et al., 1969; Morley et al., 1999). Stabilization appears to have occurred between 3,600 and 3,000 Ma. for the Tanzanian Craton (McConnell, 1972; Kroner, 1977; Morley et al., 1999), and at about 1,820 Ma. for the Zambian Craton (Brewer et al., 1979; Morley et al., 1999). Crustal thickness of the cold and rigid cratons may reach 50–60 km. The rift structure at the largest scale is controlled by the presence of these cratonic areas, both the western and eastern branches lie within the orogenic or mobile belts that surround the Tanzanian Craton (McConnell, 1972; Morley et al., 1999).

The orogenic belts display three main episodes of deformation. The oldest is the Eburnean (2,100–1,800 Ma.). It is important for creating the approximately 140° striking ductile metamorphic fabric that deflects the rifts from a north-south orientation to an northwest-southeast orientation in the western rift branch between Lakes Tanganyika, Rukwa, and Malawi.

The Kibarian Orogeny (1,400–900 Ma.) forms north to north northeast trending zones of ductile deformation. In particular, one chain (Karagwe-Ankole) forms the basement to the northern Tanganyika-Lake Kivu area (Morley et al., 1999).

The Panafrican or Katangian Orogeny of about 600 Ma., created the most widespread orogenic belts including the crystalline basement which underlies the Kenya Rift (McConnell, 1972; Smith and Mosley, 1993; Morley et al., 1999). In the western branch the orogeny is represented by the Bukoban Belt, which is relatively weakly deformed and includes platform sedimentary rocks, that are exposed on the eastern side of Lake Tanganyika (Holmes, 1952; Daly, 1984; Morley et al., 1999).

4.0 ASSOCIATED MINERAL RESOURCES OF EAST AFRICAN RIFT SYSTEM

4.1 Petroleum Resources

Recent discoveries of oil and natural gas in East Africa have created excitement throughout the region over the potential windfall of revenues into government coffers (Mwangi and Zenia, 2016). Uganda has a reserve of 2 billion barrels of oil and expected government revenues of $3.2 billion per year for the period from 2010 to 2040 (Wiebelt et al., 2013). In Kenya, there will be $10 billion in government revenue during the anticipated 30-year production period (Mwangi and Zenia, 2016). In Tanzania, natural resources have the potential to create $2.5 billion in yearly government revenues. And in Mozambique, World Bank estimates show that, by 2032, resource revenues could reach $9 billion, accounting for 21 percent of total revenues (World Bank, 2014).

According to Lyne (Unknown), the East African Region has a total of 28 prospective sedimentary basins with over 37 international oil and gas companies licensed in the region to date. The petroleum resources in the East African region are estimated at 2 billion barrels of oil in place and 3tcf of natural gas. Additional resources continue to be firmed up by aggressive exploration programmes in the region. Lyne made a summary of the petroleum potentials in the east African region as follows:

Uganda: There are six sedimentary basins in Uganda, out of which the Albertine Graben is the most prospective for petroleum exploration. The Graben forms the northernmost part of the western arm of the East African Rift System, stretching from the border with Sudan in the north to Lake Edward in the south, a distance of over 500km. The graben averages 45km in width and covers an area in excess of 22,000km2 in Uganda. Currently, the graben is subdivided into ten Exploration Areas (EAs), out of which five are licensed. The companies operating in Uganda include Tullow Oil plc, Heritage Oil and Gas Ltd, Tower Resources Ltd and Dominion Petroleum Ltd. Licensing has been suspended since early 2006 awaiting update of the country's regulatory framework for the upstream petroleum sector.

Burundi: Various studies have been conducted since 1959 for petroleum exploration both in the Rusizi basin and in Lake Tanganyika. These basins are part of the East African Rift System and are situated between Burundi, Democratic Republic of Congo, Tanzania and Zambia. This Rift System is dated from Cenozoic (Tertiary) and is divided into two branches; the eastern arm and the western arm. Lake Tanganyika and the plain of Rusizi belong to the western branch which consists of a series of sedimentary basins marked by deep lakes (lake Malawi, lake Tanganyika). In Burundi the basins cover a size of 2,968 km2. Gravity, aeromagnetic and seismic surveys have been conducted in the two basins and the average sediment thickness is estimated to be more than 3,000 metres. The exploration areas of Rusizi and Lake Tanganyika basins have been divided into four blocks: A (793.1 km2), B (697.1 km2), C (664 km2) and D (813.4 km2). Block A is Rusizi basin which is an onshore area while B, C and D are in Lake Tanganyika, from north to south respectively.

Kenya: Exploration for oil and gas in Kenya has been going on sporadically since the 1950s. The country has four sedimentary basins, namely Lamu, Anza, Mandera and Tertiary Rift. The total area under sedimentary cover is approximately 400,000km2. In these sedimentary basins which cover both onshore and offshore areas, a total of 73,392 line km of 2D seismic data has been acquired. In addition, 820 square km of 3D seismic data has been acquired in the offshore parts of the Lamu Basin. The total number of oil exploration companies operating in the country stands at 12 while the number of licensed blocks is 22, out of the total number of 36 current exploration blocks.

Rwanda: Situated in east-central Africa, Rwanda is a landlocked country bordered in the west by the Democratic Republic of Congo, in the north by Uganda, in the east by Tanzania, and in the south by Burundi. With the total area of 26,338km2, Rwanda has a population of 10 million. Steep mountains and deep valleys cover most of the country. Lake Kivu in the northwest, at an altitude of 1,472m, is the highest lake in Africa. Extending north of it are Virunga Mountains, which include Volcano Karisimbi (4,324m), Rwanda's highest point. As part of the western branch of the East African rift valley, Lake Kivu was formed in the course of the emergence of the Virunga volcano chain. This lake contains an enormous quantity of dissolved gas: an estimated 250 billion m^3 of carbon dioxide (CO_2) and 55 billion m^3 of methane (CH_4).

Tanzania: Tanzania has over 400,000km2 of sedimentary basins which cover the coastal basin, deep sea basins and inland basins. Various studies have been undertaken since 1952 for petroleum exploration in the basins. Forty-five exploration and development wells have been drilled. Over 24,000km and 65,000km of 2D seismic data has been acquired onshore and shelf, offshore as well as inland lakes. Recently over 7,000km2 of 3D seismic data has been acquired in the deep sea. Exploration studies together with well drilling done in Tanzania have resulted in discoveries of four gas fields of which two are under production and the other two being under appraisal. Gas reserves for all discoveries are estimated to be in the order of 3 tcf. Gas production from the Songo Songo and Mnazi Bay gas fields which commenced in 2004 and 2006 respectively and the gas use for industries and electricity power generation have motivated further exploration throughout the sedimentary basins in the onshore, offshore and deep sea to unveil more gas resources and oil.

4.2 Solid Mineral Resources

Most east African countries are richly endowed with a variety of mineral resources.

Burundi is well endowed with deposits of nickel, vanadium, cassiterite, colombo-tantalite, gold, uranium, rare earth oxides, peat, cobalt, copper, platinum, hydropower, niobium, tantalum, gold, tin, tungsten, kaolin and limestone.

Kenya has four belts of minerals - the gold green stone belt in western Kenya, which extends to Tanzania; the Mozambique belt passing through central Kenya, the source of Kenya's unique gemstones; the Rift belt, which has a variety of resources including soda ash, fluorspar and diatomite; and, the coastal belt, which has titanium.

Rwanda has deposits of cassiterite, a tin ore, which is a very important ingredient of electronics components. The mineral is also found in Walikale, in DRC's Northern Kivu Province, a part that borders Rwanda in the east. Other potentially profitable minerals include wolframite, columbite-tentalite, amblygonite and tantalite (colttan). Gold has also been explored in some parts of the country. Some semi-precious stones including tourmaline, topaz, corundum, chiastolite, amethyst, opal and agate have been discovered.

Tanzania has a wide variety of minerals including diamonds, gold, base metals, gemstones (including the unique Tanzanite) and a variety of industrial minerals (such as phosphates, mica, gypsum, limestone, graphite, quartz and vermiculite) that have a wide range of applications in ceramics, pottery, brick and tile-making, and glass manufacture as well as nickel, cobalt, copper, apatite, niobium, iron ore and coal.

Uganda also has a variety of mineral resources including copper, cobalt, tin, iron ore, tungsten, beryllium, limestone, phosphates, salt, clays, feldspar, diatomite, silica sand, glass, sand gravel, and construction materials such as granites and gneisses.

Investment opportunities exist in mining stone for the construction and building industry, phosphates for agriculture, salt for domestic and chemical uses, iron ore for the iron and steel industry, kaolin for leather tanning and pharmaceuticals, and silica sand and trona for glass manufacture; exploration and development of mineral deposits including oil, gold, copper, cobalt sulphide and hematite iron.

4.3 Geothermal Resources

The geothermal activity in the East African rift system is closely tied to the occurrence of Quaternary volcanoes located within the axis of the rifts (Geothermal Energy Association, 1999). The shield volcanoes are largely made of trachytes, rhyolites and associated pyroclastics. The presence of the silicic products attests to the occurrence of shallow magma (fossil) bodies that are considered the most important heat sources for the associated geothermal systems. Using today's technology, Eastern Africa has the potential to generate 2500 to 6500 MW of energy from geothermal power (GEA, 1999) which if developed would represent from ¼ to ¾ of current worldwide production from geothermal sources (8.200MW total installed capacity). Despite this potential, only Kenya and Ethiopia have active geothermal exploration and research have been undertaken in Djibouti, Eritrea, Uganda, Tanzania, Zambia and Malawi. The potential to use geothermal energy for grid-connected electrification is greatest in Kenya, Djibouti, Ethiopia, Uganda and Tanzania. In addition, all the countries have the potential to use geothermal energy for grid connected electrification (GEA, 1999).

Table 1: Mineral resources as per country.

Country	Mining & Processing
Tanzania	Gold, Iron Ore, Nickel, Copper, Cobalt, Silver, Diamonds, Tanzanite, Ruby, Garnet, Limestone, Soda Ash, Gypsum, Salt, Phosphate, Coal, Uranium, Gravel, Sand & Dimension stone
Kenya	Copper, Gold, Iron Ore, Zircon, Titanium & Zirconium, Hematite, Ilminite, Nickel, Cobalt, Zinc, Lead, Soda Ash, Fluorspar, Diatomite, Vermiculite, Gemstones
Uganda	Diatomite, Feldpar, Granite,Graphite, gypsum, Kaolin, Kyanite, Limestone, Marble, Mica, Phosphates, Rock salt, Silica sand, Talc, Vermiculite
Rwanda	Cement, Columbite, Gold, Natural gas, Peat, Tin, Tungsten
Burundi	Gold, Niobium, Peat, tin, Tungsten
Ethiopia	Clays, Coal, Columbite, Diatomite, Feldspar, Gemstones, Gold, Gypsum, Lime, Platinum, Salt rock, Silver, Soda ash, Dolomite, Granite, Ignimbrite, Limestone, Marble, Rhyolite, Sand, Scoria, Iron ore
Somalia	Gold, Natural Gas
Mozambique	Aluminium, Beryl, Clays, Coal, Diatomite, Gemstones, Gold, Natural gas, Niobium, Quarts, Sand, Garnite, Limestone, Marble, Titanium, Zirconium

Source

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5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The East African rift system can be regarded as a unique succession of graben basins linked by intercontinental transforms and segmented by transfer zones and accommodation zones. This is a lithospheric scale structure, characterized by uplift of hot asthenospheric elongate diapirs across the upper mantle, responsible for shoulder uplifts forming an intracontinental ridge system, several hundreds of kilometers wide, several thousands of kilometers long, quite equivalent to an oceanic ridge system. By its size, structure and occurrence of oceanic lithosphere in the Afar, the EARS can be taken as a model of the beginning of oceanic opening inside a continent.

There appears to be widespread agreement that the East African Rift System developed above a mantle plume on the basis of origin (Ring, 2014). Plume activity caused flood basalt volcanism in Ethiopia by about 31- 30 Ma (Ring, 2014). Africa then slowly moved over that plume and extensive volcanism affected Kenya down to the border with Tanzania. Because of the northward drift of Africa, the Eastern Branch shows this distinct evolution from initial rifting stages in the South (Tanzanian Divergence Zone), via mature stages in the Kenya Rift to incipient continental break-up in the Ethiopian/Afar section (Ring, 2014). With respect to mineral resources, few studies in details have been conducted to present inherent minerals in the east African rift system. The major country in the area are Tanzania, Kenya, Uganda, Ethiopia, Mozambique, Somalia, Burudi and Rwanda. This country collectively cover an area of about eight million square kilometers.

Moreover, the East African Rift System is a complicated system of rift segments which provide a modern analog to help us understand how continents break apart. It is also a great example of how many natural systems can be intertwined - this unique geological setting may have altered the local climate which may have in turn caused our ancestors to develop the skills necessary to walk upright, develop culture and ponder how such a rift came to be. Just like the Grand Canyon, the East African Rift System should be high on any geologist's list of geologic marvels to visit.

The mineral resources that occur in the area include: gold, hematite, nickel, diamond, limestone, coal and natural gas.

5.2 Recommendations

It is hereby recommend that:

a) East African Rift System Research and Development Commission should be established with Headquarter in one of the countries to coordinate researches relating to Geology and Mineral Resources of the area.
b) Further studies should be conducted on the petroleum and geothermal energy resources of the area.
c) Relevant functional environment-related agencies should be established to ensure sustainable development of solid minerals/natural gas that occur in the area.

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