

EAST AFRICAN RIFT SYSTEM - AN OVERVIEW

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ABSTRACT

The main characteristics of the East African Rift System are outlined from selected references. The difference between the Eastern Rift with high volcanicity on two domal uplifts as against the Western Rift of restricted volcanism, but sediment and lake filled grabens is pointed out. This is also evident from the earthquake activity: Large earthquakes occur in the Western Rift, whereas earthquake swarms of mostly microseismic activity characterize the Eastern Rift. The difference is significant for the geothermal potential of the region. The high temperature geothermal systems are closely related to volcanic centres. High volcanoes are not easily accessible for developing geothermal reservoirs in their roots. But hot outflows at lower ground near to them may prove significant, however, of lower temperature. By mapping a volcanic system as a whole and defining a related fissure swarm of faults and eruptive fissures, local concentration of high activity may show up as possible geothermal targets.

1. INTRODUCTION

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 (Figure 1).

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 rifts of the Red Sea and the Indian Ocean Ridge meet. The East African Rift System forms the third arm, a complex feature with two main rift branches, the Western and the Eastern Rifts Figure 2. 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 1000 km wide. It has also three rift arms,

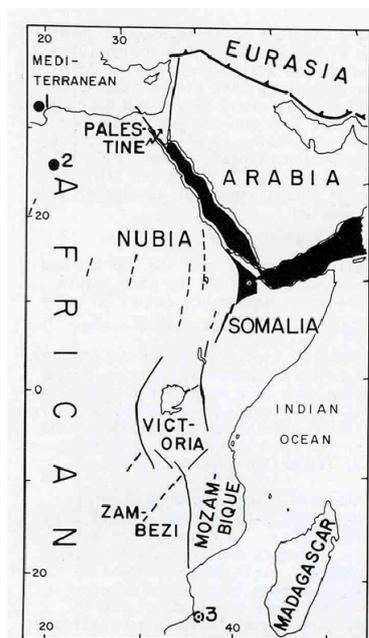


FIGURE 1: Plate tectonics of the Afro-Arabian rift system. Black areas marked neo-oceanic crust formed by spreading within this system. Solid lines mark plate boundaries; dashed lines mark intraplate zones of deformation. (From: Baker, et al., 1972)

two of them forming the main rift, the third (Kavirondo) subdued trending west from the centre of the dome (Figure 3). 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.

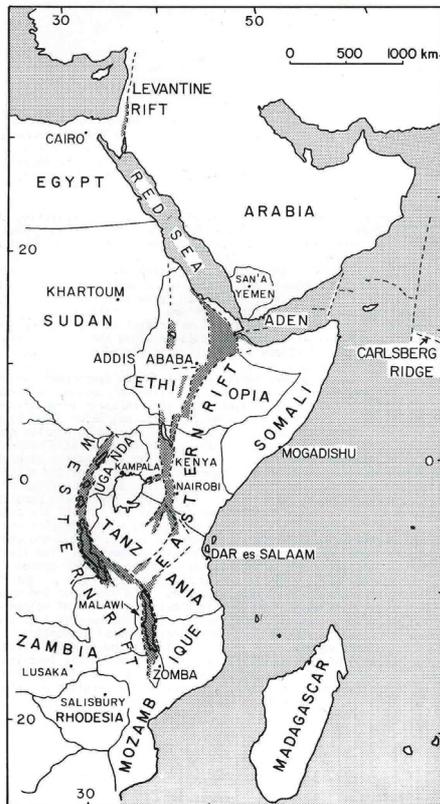


FIGURE 2: The Afro-Arabian rift system (continental graben and depressions are shaded) (From: Baker et al., 1972)

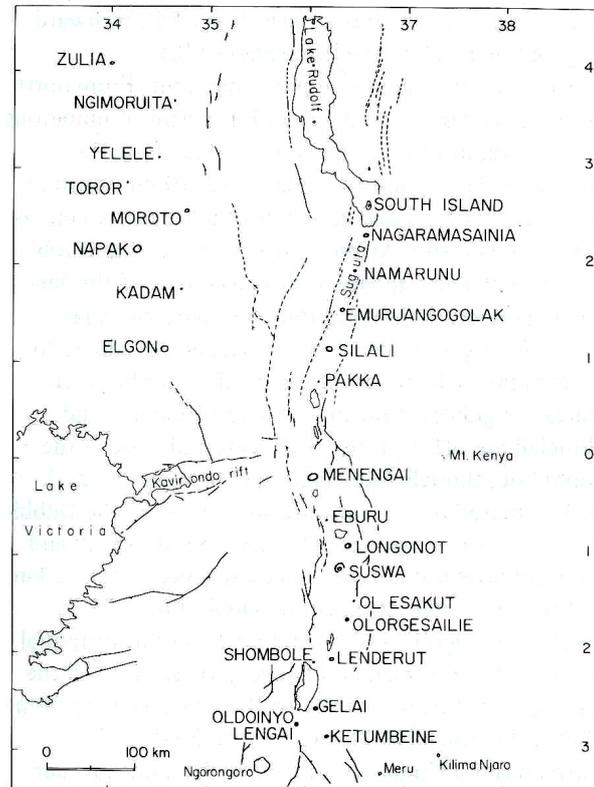


FIGURE 3: The Pliocene-Quaternary volcanoes of the Gregory rift axis, and the Miocene alkaline centres of eastern Uganda. Major boundary faults of the rift are also shown. Source map for this figure is the unpublished "Geological Map of the East African Rift Valleys" (1:2 million) (From: Mohr and Wood, 1976)

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 (Figure 4). 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 over 1400 m) but volcanism is subordinate although hosting Africa's most active volcano in the Virunga mountains (Figure 5).

2. GEOLOGY

The rift valleys are a system of normal faults bordering a 40-60 km wide trough, funnelling out toward north in the Afar region. The Kenya Rift diverges into splays towards north (Turkana) and south Tanzania (Figure 6 and 7) (Baker et al). Domal uplift and extension causes the brittle crust to fracture into a series of normal faults giving the classic horst and graben structure of rift valleys.

In Djibouti and Ethiopia volcanic and rifting episodes are known to occur, involving magmatism and widening of discrete volcanic systems. The last occurred in 1978 (Ardukoba) and 2005 to 2008 (Dabbahu) (Figure 8). Recurrence times are unknown. Those are controlled by the rifting process:

stress builds up for a long period of time (centuries) to breaking limit. Overstretched zone of weakness opens up along pre-existing faults and basalt intrudes into them at depth (dyking). Fissure eruptions may occur depending of magma supply. The caldera (central) volcanoes of the rift are underlain by crustal magma chambers during some stages of their active periods. They erupt silicic magma when overpressure breaks their roof – either as large volume pyroclastics or smaller volume domes and flows. A variety of central volcanic activity is long lasting eruptions or lava lake activity of basaltic lava at their central crater.

Spreading slows down from north to south from 2.6 cm/yr in the Red Sea to about 1 cm/yr in Afar to 0.7 cm/yr in the Ethiopian Rift and 0.5 mm/yr combined in the Western and Eastern Rifts across the Kenya Dome and gradually decreasing from there to the south. For comparison: North-Atlantic has a spreading rate of 2.3 cm/yr and Iceland 1 cm/yr. Those are half-rates.

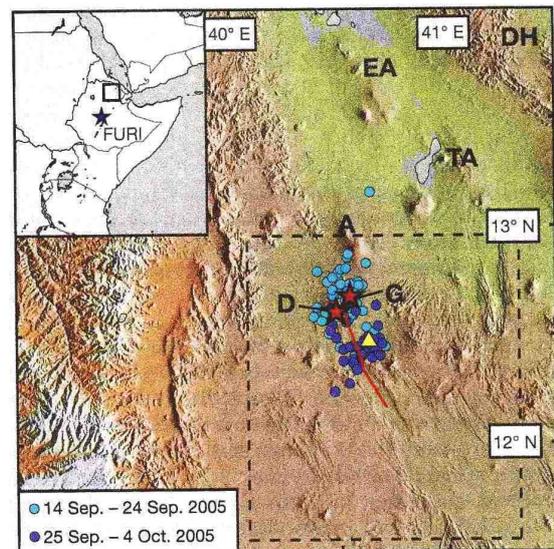


FIGURE 8: Red line shows location of dyke and red stars mark Dabbahu volcano. (From: Wright, et al., 2006)

There is a close association between doming, rifting and alkaline magmatism/volcanism. Figure 9 shows the estimated volumes involved for the Eastern Rift. The development sees four magmatic episodes correlating with tectonic phases beginning in the Miocene. The first appearance of the development phases was:

- 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 (Figure 10).
- 3) Pliocene. Doming of about 1400 m. Main rifting. Graben faulting. Trachytes in rift floor (Southern Kenya Rift). Basaltic volcanism (Figure 11 and 12).
- 4) Quaternary. Major graben faulting, caldera volcanoes in axial zone Basalt phonolite volcanism in off-rift volcanoes beginning in Upper Pliocene (Figure 13).

Figures 10-13 are from Baker and Wohlenberg (1971).

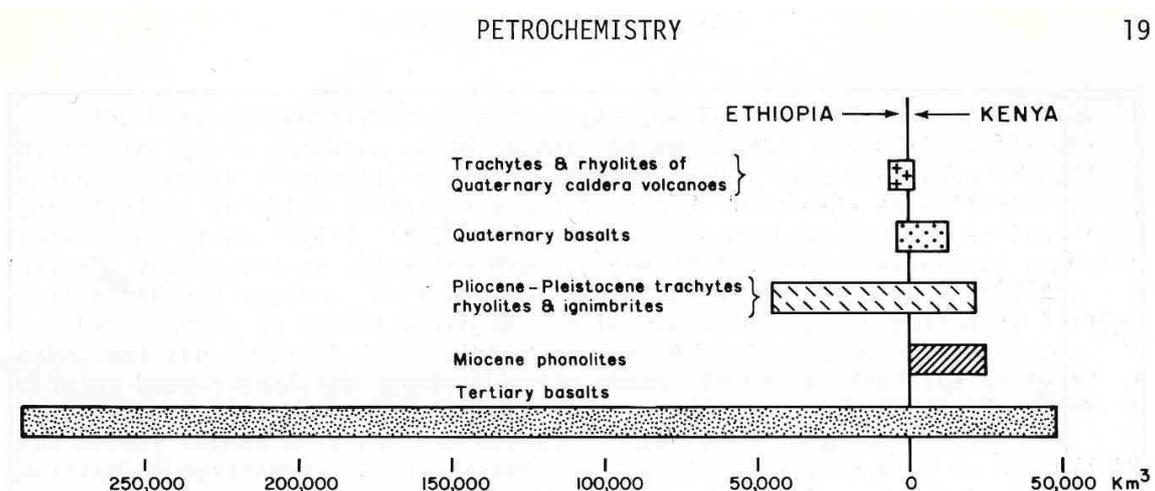


FIGURE 9: Estimated volumes of eastern rift volcanics (From: Baker et al., 1972)

This sequence represents a progression from 1) incipient melting of the upper mantle associated with early uplift, through 2) extensive partial melting of the uppermost mantle and lower crust giving rise to phonolites to 3) and 4) pervasive partial melting of the lower crust due to lowering of the central rift segment into the heated zone causing trachyte outpourings (Bailey 1974).

The formation of rift fractures initiates magmatism, the volume and composition of the volcanics being controlled by the opening rates. At rates of less than 1 mm/yr there is little or no volcanism. At rates of 1-10 mm/yr alkaline to mildly alkali line basalts appear accompanied by large volumes of peralkaline silicics and rates of 1-2 cm/yr correlate with large volumes of transitional basalts with subordinate peralkaline silicics.

The first eruptive rocks in the cycle, seen in Ethiopia and Kenya, were extensive alkali flood basalts generated from melts at depths of about or greater than 35 km. More saturated basalts (transitional between alkaline and tholeiitic) followed in the rifts generated at shallower depth. A final stage with full scale separation of the continental blocks and tholeiitic magmatism forming new oceanic crust has been reached in the Afar triangle (Figure 1).

The sequence of igneous rocks related to the rift development was controlled by the progressive rise of geo-isotherms in the crust.

The high temperature geothermal resources are closely related to the volcanic centres, both at the pre caldera stage (Korosi) and in particular their calderas. This bears relation to the crustal magma chambers which feed their silicic volcanic production. Very often the prospects are at high ground elevations where production may be difficult and sufficiently high pressures may not be possible. The fissure swarms which extend from them are likely to be fed laterally. They are less likely as hosting a significant (i.e. very hot) geothermal resource. Concentrations of volcanic eruptions on the swarms may indicate a resource, however.

3. GEOPHYSICS

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).

Seismic data suggest that the East African rift system is a zone of shallow earthquakes (average focal depth 20 km). 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 (Figure 14). In the Eastern Rift seismic activity seems to be more concentrated in swarms of certain areas.

Gravity surveys of the East African rifts show a progressive change from north to south in accordance with crustal separation and magmatic intensity. In the Red Sea where crustal separation is significant and dense material has intruded upwards the gravity (Bouguer) anomalies are highest. 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.

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. In geothermal prospecting it is helpful in outlining areas of altered rocks as the magnetite in them is destroyed.

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).

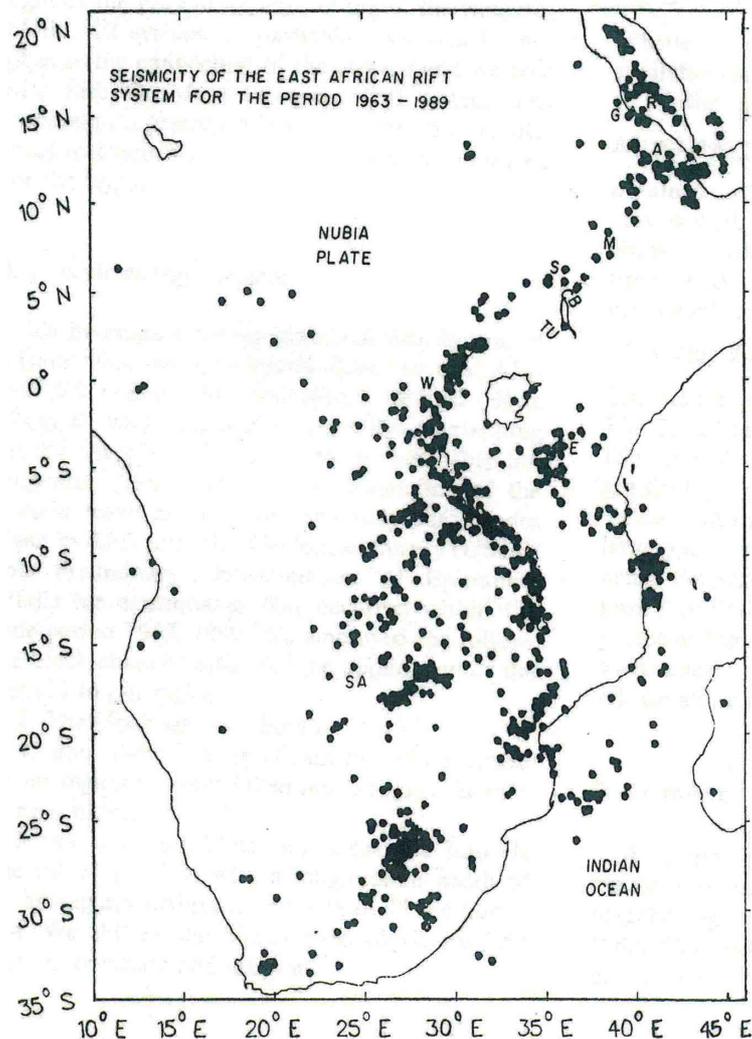


FIGURE 14: Seismicity of the East African Rift system and southern Red Sea for the period 1963-1989. Solid circles denote earthquake epicentres taken from National Oceanic and Atmospheric Administration (NOAA) catalogue, R, G, A, M, S, W, E and SA denote southern Red Sea, Gulf of Zula, Afar depression, Main Ethiopian Rift system, southernmost rifts of Ethiopia, western rift, eastern rift and the southern part of the East African Rift system, respectively and are intended to indicate the corresponding rift subsegment. CB and TU indicate location of Chew Bahir and Turkana grabens, respectively. Closed regions in the figure show large lakes in the rift
(From: Kebede and Kulhánek, 1991)

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