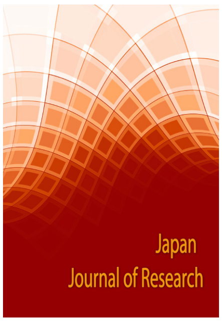
Japan Journal of Research

Review Article



East African Rifting; Seismic Contribution

ELOUMALA ONANA Parfait Noel[1], FEUMOE Alain Narcisse[2], NJITEU TCHOUKEU Cyrille Donald[1], EBODE Brice Valentin[3], NGATCHOU Evariste[3], EMVOUTOU C Huguette[4], MOUZONG Pemi Marcelin[1]

[1]University Institute of Technology, University of Douala, Cameroon
[2]Faculty of Engineering and Technology, University of Buea, Cameroon
[3]High teacher Training College, University of Yaoundé-I, Cameroon
[4]Sciences Faculty, University of Douala, Cameroon

Correspondence
Parfait Noel ELOUMALA ONANA
University Institute of Technology,
University of Douala, Cameroon

- Received Date: 17 June 2026
- Accepted Date: 29 June 2026
- Publication Date: 03 July 2026

Keywords

EARS, seismicity, Swarms, faults, magma, Mb, Ms

Abstract

This study interprets the rifting mechanism and lithospheric state within the East African Rift-System, revealing a system in moderate state, active extension distension driven by distributed strain and magma-assisted rifting. Analysis of a six-month seismic catalog shows that seismicity is predominantly low-to-moderate in magnitude (Mb: 3.7 to 4.5), with a maximum of Ms up to 5.3. The absence of large-magnitude events (M > 7) indicates that regional extension is accommodated incrementally through a steady sequence of moderate earthquakes and secondary processes, such as magmatic intrusion and creep, rather than the catastrophic release of massive stored stress.

A pronounced Mb-versus-Ms discrepancy where Ms is significantly higher, points to shallow focal depths and longer rupture durations. This shallow nature of seismicity is further reflected in the catalog with 0.0 km fixed depth data artifacts, confirming that considerable tectonic energy originates within the uppermost crust (1–2 km). Crucially, a near-total absence of seismicity below 12 km identifies a remarkably shallow brittle-ductile transition zone. This compressed brittle layer indicates an elevated geothermal gradient and active lithospheric thinning, where an upwelling asthenosphere heats the lower crust, forcing it to deform plastically. Consequently, the tectonic forces are entirely localized within a thin, highly fractured upper crust from 0 to 15 km. Unable to store the considerable elastic strain required for large events, this brittle upper crust fails frequently and easily along a network of normal faults, effectively bleeding off tectonic energy through continuous moderate swarms.

Introduction

The East African Rift-System (EARS) is a massive crack in the crust that stretches for over 6,000 kilometers from the Afar Triple Junction in the north to Mozambique in the south. It is an important geological structure which is visible from space [1]. This active continental rift zone splits the African Plate into the Somalian to the East and Nubian to the West [2] at a rate of 6–7 mm per year. This movement is slowly pulling Africa apart, forming divergent boundaries between the plates [3].

Its tectonic activity is characterized by three main phases: First phase in Early Paleogene, which usually characterizes a perpetuation of rifting from the Late Cretaceous [4]); the second phase since the Oligocene to Early Miocene age and the third and current active set of rifts, dating, to the Mid Miocene (since early Paleogene). Broadly bifurcated by the stable, ancient Archean Tanzanian Craton, the system splits into two distinct structural trends: the magma-rich Eastern Branch (encompassing the Ethiopian and Kenyan rifts) and the deep, fluid-lacustrine Western Branch [5].

While the surface topography of the EARS is dynamically shaped by massive border fault systems and asymmetric half-grabens [3], its deep driving mechanisms remain a subject of active geophysical debate. Global seismic tomography and geodynamic models reveal that the rift is intimately tied to a broad, lower-mantle thermal upwelling known as the African Superswell [1]. This phenomenon feeds intrusions into the mantle, inducing thermal uplift and weakening the continental lithosphere along ancient Precambrian structural fabrics [3,1].

Seismic studies play an invaluable role in unraveling these underlying geodynamic complexities. By deploying ambient noise and teleseismic surface-wave tomography, geophysicists have begun mapping high-resolution shear-wave variations beneath the rift branches [5]. This allows researchers to capture clear snapshots of upper-mantle thinning, crustal stretching, and structural segmentation along the EARS axis.

This paper builds upon previous seismic investigations to explore the deep structural variations and crust-mantle coupling within the EARS. Understanding the seismicity of

Citation: ELOUMALA ONANA PN, FEUMOE AN, NJITEU TCHOUKEU CD, et al. East African Rifting; Seismic Contribution. Japan J Res. 2026;7(4):188.

this region is crucial for modeling the geodynamic processes leading to continental breakup. By examining a seismic catalog derived from data collected by the International Monitoring System and analyzed by the International Data Centre, this study aims to better resolve the relationship between magmatic intrusion and mechanical faulting, ultimately refining our understanding of how continents tear apart.

Geomorphological setting

The East African Rift-System (EARS) is one of the most geologically significant features on the Earth. It is an active continental rift zone which splits where the African Plate into two plates: the Nubian Plate to the west and the Somalian Plate to the east. This process is a typical example of how continents break apart, potentially leading to the formation of a new ocean in millions of years. The rifting took place from the boundary faults to the center of the system [6]. In the crack floor, the extension is leading by an important magmatic activity [7].

The EARS is primarily composed of two distinct branches [8]:

- The Eastern Rift Valley, called the Gregory valley, runs from the Afar in Ethiopia to Kenya and to the north of Tanzania. It is a magmatic-dominated rift characterized by extensive volcanism and high heat flow [9].
- The Western Rift Valley, called the Albertine Rift, extends north from Lake Malawi in a great arc, including lakes such as Albert, Edward, Kivu, and Tanganyika. This branch is generally less volcanic but more seismically active and features some of the world's deepest freshwater lakes [10].

Afar Triple Junction is a crucial area where the transition from continental crust to the oceanic crust is spreading [3].

The geomorphology of the region is driven by extensional tectonics. As the crust is pulled apart, several distinct geological phenomena occur: rifting is likely driven by mantle plume upwelling of hot rock within the mantle of the earth. This heat causes the overlying crust to expand and rise, creating broad topographic highs like the Ethiopian Highlands. As the crust stretches, it thins and undergoes normal faulting in the form of grabens and horsts.

The EARS is home to some of the most unique volcanic landforms of the world. Because the crust is thinning, magma can easily reach the surface. Stratovolcanoes such as Mount Kilimanjaro and Mount Kenya sit on the shoulders or within the rift. At the northern end, the rifting has progressed so far that the crust is almost oceanic with basaltic event and silicic magmatism (Tyrone O., 2020)..

The rifting has radically altered the drainage patterns of Africa. As Endorheic Basins, many rift valleys create closed basins where water does not flow to the sea. This leads to the formation of saline soda lakes as Lake Natron, due to high evaporation and volcanic mineral input. The Western Rift contains some of the deepest lakes in the world. Lake Tanganyika is the second deepest lake on Earth, formed because the rift floor has dropped far below sea level, even if the water surface is high.

Tectonic Stress and Seismic Setting

The seismic regime of the EARS is dominated by normal faulting, indicating a regional extensional stress field oriented perpendicular to the rift axis [11]. In the central sectors, such as the Kenya Rift, focal mechanisms show a predominantly WNW–ESE extensional stress, generating normal faults that trend parallel to the NNE–SSW rift alignment. While the bulk of seismic energy is released along the axial structures, notable off-rift seismic clusters exist, demonstrating stress redistribution across the boundary zones of margins.

In the Eastern Rift Valley, seismicity is typically moderate, highly localized, and shallower (≤ 15 km), tightly bound to active magma plumbing systems and hydrothermal centers [12,13]. In Western Rift Valley, seismicity is deeper, extending into the lower crust down to 30-40 km, and exhibits higher-magnitude tectonic earthquakes due to thick, strong lithosphere and deep-seated mechanical faulting [14]. The north part, specifically the Main Ethiopian Rift (MER), captures a critical evolutionary transition from tectonic-dominated rifting to incipient seafloor spreading [15].

During the Quaternary, the extensional stress migrated away from the faults border of Miocene and focused into a narrow, wide axial zone of about 20 km, called Wonji Fault Belt (WFB) [15,13]. The WFB is a dense network of normal faults and active volcanic fields [16].

Seismicity within the WFB is characterized by high rates of low magnitude microseismic events and seismic clusters [17] which is largely influenced by subsurface fluid migration [18], dyke intrusions, and hydrothermal fracturing [13]. Although high-slip rates (~ 2.0 mm/year) indicate that extension along the WFB is heavily accommodated by magmatic processing, historical earthquakes (M > 6) occurring along the older border faults highlight the complex coexistence of magmatic dyking and brittle tectonic faulting across the rift segment [16].

Data and Observations

Events from our dataset were collected from International Seismological Center (ISC)on one hand and on others hand were recorded by the International Monitoring System (IMS) using its global network designed for high-fidelity signal detection (Table enclosed). By leveraging advanced analytical frameworks of IMS, this paper interprets the recorded catalogue to provide insights into crustal dynamics of the region and stress distribution. The following sections analyses recent seismicity and the subsequent geodynamic implications.

Initially, our search focused on recording seismic events within the geographic region bounded by 35° to 42° longitude and 2° to 12° latitude. Finally, we obtained a distinct cluster of seismic activity localized in the northern part of the EARS, as illustrated in Figure 1. Notably, this particular area was the only region active throughout the study period, indicating a concentrated zone of tectonic and volcanic activity.

The majority of these seismic events were recorded by a diverse network of monitoring stations, including local, regional, and teleseismic stations. This wide range of observational coverage ensured a comprehensive dataset, capturing seismic signals at varying distances and enhancing the accuracy of event localization and characterization. This study presents a detailed evaluation of seismic data acquired over a continuous six-month observation period, covering from December 2024 to March 2025.

Magnitude Distribution

The catalog shows a predominance of events with magnitude (Mb) between 3.7 and 4.5. However, several significant events reach magnitude (Ms) 5.3 (Table 1).

The presence of M > 5 events indicates that the rift is capable of generating significant elastic strain release. The lack of very large events (M > 7) in this specific window suggests that

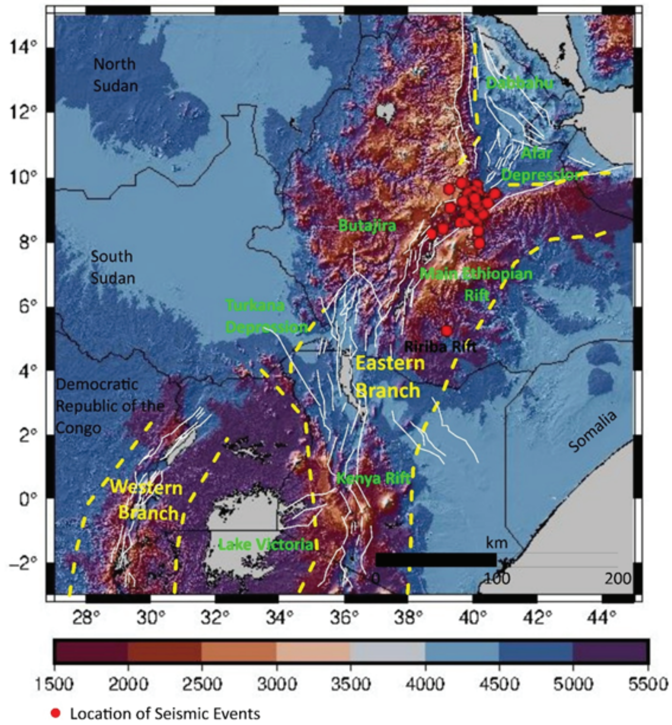


***Figure 1**: Distribution of seismic events detected and recorded by IMS stations*

oceanic expansion is largely accommodated by a combination of frequent moderate earthquakes and possibly aseismic creep or magmatic intrusion.

Hypocentral Depth Analyses

A defining characteristic of the data is the shallow nature of the seismicity. A vast majority of the events are located at 0.0 km fixed surface depth, or within the upper 12 km depth.

In rifting environments, the brittle-ductile transition is often shallow due to high heat flow from upwelling asthenosphere. The occurrence of events in the upper 10–15 km suggests that the upper crust is highly fractured and that the thinning of the lithosphere has localized tectonic stress in a very thin brittle layer.

Spatial Clustering and Azimuth

Episodic swarms are noted, with azimuthal values often clustering around 150°–170°. These azimuthal gaps and alignments correspond to the NNE-SSW trending Wonji Fault Belt. The alignment confirms that tectonic activity moved from the margin faults of the rift to the axial segments of the rift floor. This observation marks a pivotal moment in the life cycle of a rift. It indicates that the crustal extension has moved past its initial phase and is now entering a more mature, magma-driven stage.

.The Migration of Strain (Border to Axis)

In the initial steps of rifting, the border faults controlled the activity. However, our data confirms that the rift has entered the Axial Phase. The tectonic stress is no longer breaking the thick crust at the edges. Instead, the rift has thinned so much in the center that the axial segments have become the weakest point. Currently, the WFB is accommodating the majority of the plate motion.

Azimuthal Clustering (150°–170°)

The clustering of azimuthal values around 150°–170° is highly significant. This NNE-SSW alignment is the fingerprint of the Wonji Fault Belt. It shows that the earthquakes are not happening randomly; they are strictly confined to the geometry of the quaternary magmatic segments. This orientation suggests that the regional extension (the pulling apart of the plates) is likely occurring in a WNW-ESE direction, perpendicular to those fault lines.

Episodic Swarms

The episodic nature of these earthquake swarms is a classic signature of diking events. Unlike a typical earthquake followed by aftershocks, swarms are many medium-sized events without a single massive one. This usually happens when magma is forcing its way into a crack (a dike) in the crust. The magma reduces friction between the rock layers and pushes it apart, causing a flurry of seismic activity along the axial segment. This confirms that the East African Rift is not just pulling apart due to tectonic force, but is being pushed apart by magmatic pressure from below.

Discussion: Interpretation

The data support a model of rifting assisted by magma uplift. In the MER, the evolution from rifting area to oceanic spreading is facilitated by diking, the injection of magma into the crust. The shallow, frequent earthquakes recorded in the catalog are likely the result of the crust adjusting to these magmatic intrusions and the regional extensional stress field.

This observation provides a clear picture of the current tectonic behavior within EARS. The data show that, the rifting is currently in moderate state of active extension rather than a catastrophic locked phase.

Energy Release and Rift Maturity

The fact that magnitudes reach Ms 5.3 confirms that the crust is brittle enough to accumulate and suddenly release significant elastic strain. In a rift context, M > 5 events are typically associated with the movement of major border faults. This indicates that the rift is tectonically active and dynamically widening.

The Mb vs. Ms Discrepancy

The predominance of Mb (3.7–4.5) suggests a high frequency of relatively small, deep, or high-frequency ruptures. Ms is significantly higher than the Mb, what indicates Shallow Focal Depths; Shallow events are more efficient at generating the surface waves that Ms measures. It also point out Longer Rupture Durations; Ms captures the lower-frequency energy of a larger, slower rupture better than the short-period Mb.

Missing Large Events (M > 7)

The absence of large earthquakes during this six-month window is effective. The crust is not breaking with large magnitude events, what means that the extension is happening through other mechanisms; the tectonic plates are sliding past or away from each other slowly and smoothly without cracking, preventing the buildup of considerable stress. In EARS volcanic rifts, the crust is weakened by rising magma. Instead of the crust breaking, it stretches or accommodates the gap with molten rock (diking). This process usually produces many moderate swarms rather than one large earthquake.

The Mb 3.7–4.5 events recorded are likely doing the heavy lifting of the expansion of the rift, releasing stress incrementally. We interpret this as a distributed strain model. The rift is not currently storing enough energy for a mega-event; instead, it is bleeding off energy through a steady drumbeat of moderate earthquakes and secondary geological processes like magmatic thinning or creep.

The 0.0 km Fixed Depth Data

Surface and shallow events observed are a critical indicator of the thermal and mechanical state of the lithosphere in our study area. The mention of events at 0.0 km is a common artifact in seismic catalogs, particularly with the IMS or global networks. When the depth of an earthquake cannot be accurately determined because it is extremely shallow or the station coverage is distant, the location algorithm fixes the depth to the surface to stabilize the horizontal coordinates. It confirms that the energy is originating very close to the surface, likely within the first 1–2 km, which is typical for active rift faulting or volcanic-tectonic interactions.

High Heat Flow and the Brittle-Ductile Transition

The fact that almost no seismicity occurs below 12 km is the most significant proof for the thermal profile of the rift. Usually, the continental crust is brittle down to about 20–30 km. However, in an active rift, the asthenosphere hot and plastically deforming layer rises closer to the surface. This upwelling heats the lower crust, making it ductile. Because ductile rock flows instead of snapping, it cannot generate earthquakes. The Brittle-Ductile Transition in the EARS is remarkably shallow. This suggests an extremely high geothermal gradient, which is a symbol of an advanced rifting process or significant lithospheric thinning.

Crustal brittle and Stress Localization

The concentration of events in the top 10–15 km suggests that the thickness of the plate is very low. The predominance of events in this narrow window suggests a shattered upper crust. The crust is not a solid block but a series of small, highly fractured fragments moving along normal faults. Since the deeper crust is too hot to hold stress, all the tectonic force of the rift must be supported by that thin layer. This explains why we have frequent moderate. The crust is too thin to store the massive amounts of energy required for a big earthquake, so it fails frequently and easily.

Conclusion

The confinement of seismicity to the upper 12 km, coupled with a high frequency of surface-fixed events, provides strong evidence for an elevated geotherm and a shallow brittle-ductile transition. This indicates that lithospheric thinning is well-advanced, localizing tectonic strain within a fragile upper crustal veneer, likely driven by significant asthenosphere upwelling beneath the East African Rift.

The observed azimuthal clustering (150°–170°) and the episodic nature of the seismicity signify a strain localization transition. The evolution of activity from the lithospheric margin faults to the axial Wonji Fault Belt suggests that the rift valley floor has become the primary zone of deformation. This behavior, characterized by swarms rather than discrete main shock-aftershock sequences, strongly implies that magmatic diking is now the dominant mechanism for crustal thinning in this segment.

References

1. Scoon RN. The East African Rift System. Geology of National Parks of Central/Southern Kenya and Northern Tanzania. 2018:19-28.
2. Glerum A, Brune S, Stamps DS, Strecker MR. Victoria continental microplate dynamics controlled by the lithospheric strength distribution of the East African Rift. Nat Commun. 2020;11(1):1-15.
3. Chorowicz J. The East African rift system. J Afr Earth Sci. 2005;43(1-3):379-410.
4. Morley CK, et al. 1999. (Reference incomplete in source manuscript.)
5. Korostelev F, Lu Y, Magrini F, Boschi L, Leroy S, Vétel W. Images of the East African Rift System by Global Adaptive-Resolution Surface-Wave Tomography. J Geophys Res Solid Earth. 2022;127(5).
6. Bilham R, Bendick R, Larson K, Braun J, Tesfaye S, Mohr P, Asfaw L. Secular and tidal strain across the Ethiopian rift. Geophys Res Lett. 1999.
7. Ebinger C, Casey M. Continental breakup in magmatic provinces: An Ethiopian example. Geol Soc Am. 2001.
8. Wolfenden E, Ebinger C, Yirgu G, Deino A, Ayalew D. Evolution of the northern Main Ethiopian rift: birth of a triple junction. Earth Planet Sci Lett. 2004;224:213-228.
9. Mohr P, Mitchell JG, Raynolds RGH. Quaternary Volcanism and Faulting at O'A Caldera, Central Ethiopian Rift. Bull Volcanol. 1980.
10. Zanettin B, Justin-Visentin E. Tectonical and volcanological evolution of the western Afar margin. 1975.
11. Hayes GP, Jones ES, Stadler TJ, et al. Seismicity of the Earth 1900-2013 East African Rift. USGS Open-File Report. 2014.
12. Ayele A, Kulhanek O. Reassessment of source parameters for three major earthquakes in the East African rift system. Ann Geofis. 2000;43:81-94.
13. Ogden CS, Keir D, Bastow ID, et al. Seismicity and Crustal Structure of the Southern Main Ethiopian Rift. Geochem Geophys Geosyst. 2021;22(10).
14. Ebinger CJ. Tectonic development of the western branch of the East African rift system. Geol Soc Am Bull. 1989;101:885-903.
15. Chiasera B, Rooney TO, Bastow ID, et al. Magmatic rifting in the Main Ethiopian Rift began in thick continental lithosphere. Lithos. 2021;406-407:106494.
16. Pizzi A, Coltorti M, Abebe B, Disperati L, Sacchi G, Salvini F. The Wonji fault belt (Main Ethiopian Rift): structural and geomorphological constraints and GPS monitoring. Geol Soc Lond Spec Publ. 2006;259(1):191-207.
17. Keir D, Ebinger CJ, Stuart GW, Daly E, Ayele A. Strain accommodation by magmatism and faulting as rifting proceeds to breakup. J Geophys Res. 2006;111.
18. Keir D, Bastow ID, Daly E, Cornwell DG. Lower crustal earthquakes near the Ethiopian rift induced by magmatic processes. Geochem Geophys Geosyst. 2009;10.