

PATTERN OF SEISMICITY ASSOCIATED WITH THE AFRICAN LITHOSPHERIC PLATE

ABSTRACT

The paper focused on earthquake distribution pattern associated with the African lithospheric plate. Knowledge of earthquake distribution pattern in African plate is essential in exploration, understanding and forecasting of earthquake occurrence in four major regions of African plate. The earthquake epicenters for these regions were mapped out from the global seismicity map. The epicenters were located on Northern Africa (latitude 20° to 40°, longitude 0° to 50°), Southern Africa (latitude -10° to -30°, longitude 20° to 40°), Eastern Africa (latitude 10° to -25°, longitude 36° to 50°) and Western Africa (latitude 0° to 7°, longitude 0° to 10°). The earthquake data corresponding with these epicenters were obtained from global earthquake catalogue. The data covered a 40-year period from January 1st 1974 to December 31st 2013 and in all, there were 58,649 earthquakes. The results obtained revealed that the Northern, Southern and Eastern regions of Africa are more prone to a significant level of seismic hazard than the Western Africa region. This signifies that the seismicity of Africa is mainly concentrated in two main regions - Northern and South-eastern Africa. This implied that the seismotectonic process is marked by a relative motion alternating between left and right lateral along the African and Eurasian plate.

Keywords: African lithospheric plate, seismotectonic, epicenter, earthquake distribution

1.0 Introduction

The seismicity of the Africa has been studied by Gutenberg & Richter (1949, 1954), Rothe (1964), Sykes & Landisman (1964) and Fairhead (1968). Their findings revealed that the

25 seismicity of Africa is mainly concentrated in two main regions: North Africa and southeast
26 Africa (Map 3). In North Africa, Algeria, Morocco and Tunisia, have a relatively moderate
27 seismicity despite the apparent tectonic activity of that thrust zone of 2,300 km long and 400 km
28 wide. This region, which comprises the Atlas ranges bordering the western Mediterranean Sea
29 and the southern Iberic peninsula, has experienced, since hundred million years ago, a common
30 tectonic evolution characterized by a relative motion between the left and right lateral along the
31 African and Eurasian plates. Most of the seismic activity in North Africa is concentrated along
32 the Atlas Mountains, mainly along the Mediterranean coast. Libya and Egypt have a low seismic
33 activity. More localized studies of African seismicity carried out by Sutton & Berg (1958), De
34 Bremaecker (1959), Wohlenberg (1968), Lahr & Pomeroy (1970), Gane & Oliver (1953), Oliver
35 (1956) and Green & Bloch (1971) revealed that the south-eastern African region covers a region
36 which is prone to a significant level of seismic hazard due to the presence of the East African rift
37 system. The whole region is crossed by a tectonically active rift system within a stable African
38 shield known as the East African Rift System (EARS). The east African Rift trends largely north
39 south, following the great lakes: Albert, Edward, Kivi, Tanganyika and Nyasa. An active branch
40 on the opposite side of Lake Victoria follows the Rift Valley of Kenya, through Lake Rudolf into
41 Ethiopia. In Ethiopia, seismic activities follow narrow zones associated with structures of the
42 Afar depression and the main Ethiopian rift. Kenya rift is almost devoid of seismic activity
43 although micro-earthquake studies in the Kenya rift have shown that the rift floor is seismically
44 active. Another highly active region on the Eastern branch is northern Tanzania. The area shows
45 diffuse seismicity that starts close to Lake Victoria and stretches south-eastwards to the Indian
46 Ocean. The Western branch is more seismically active than the Eastern branch. In the northern
47 end, seismicity dies out abruptly in southern Sudan as the rift encounters the Aswa Shear zone.

West of Lakes Edward, Kivu and Tanganyika in Zaire and Zambia, the seismicity is diffuse. The southern extension of the Western branch is well defined by a seismicity belt running through Malawi to southern Mozambique. Kariba is the most seismically active area in this part of the region.

1.1 African Plate

African continent is one of the few land masses where very few earthquakes have been reported. It was not until fairly recent that the data on the African earthquakes began to appear in scientific publications. At present, the African plate is the third largest tectonic plate (~60 million km²) with approximately half of it covered by land. This plate comprises several old cratonic units and accreted younger crust, representing a period of more than 2.5 billion years of continental and oceanic crust growth (e.g. Burke, 1996). The African plate (as shown in figures 1, 2 and 3) moved relatively slowly for the last 150 Ma (Lithgow-Bertelloni and Richards, 1998; Torsvik et al., 2010). However, its continental interior experienced many changes throughout this time including rifting and variations in sedimentary basin subsidence, most of them in regions situated thousands of kilometers away from plate boundaries. The African plate was also partly underlain by mantle with above the average temperature—either induced by a series of hotspots or a superswell, or both—that contributed to episodic volcanism (including several Large Igneous Provinces—LIPS), basin-swell topography, and consequent sediment deposition, erosion, and structural deformation (e.g., Bumby and Guiraud, 2005). Long-term intra-continental crustal deformation may be related to local and regional tectonic events (e.g., Cloetingh and Burov, 2011; Zoback et al., 1993) and mantle-lithosphere interaction (e.g. Heine et al., 2008). Far-field stresses related to changes in plate boundaries are able to propagate within the lithospheric plates over thousands of kilometers and therefore may trigger rifting, folding and changes in

sedimentary basin subsidence rate in remote regions (e.g. Xie and Heller, 2009). The relationship between plate boundary forces and observed deformation within plate interiors has been studied for several large tectonic plates and numerous authors attempted modelling and quantification of ensuing present day and palaeo-stresses resulted from this connection: North America (e.g. Faure et al., 1996), South America (e.g. Meijer and Wortel, 1992), Africa (Meijer and Wortel, 1999), Eurasia (e.g. Nielsen et al., 2007; Warners-Ruckstuhl et al., 2012), Australia (e.g., Coblentz et al., 1995; Dyksterhuis and Muller, 2004), and Pacific (e.g. Faccenna et al., 2012; Wortel et al., 1991).

2.0 Materials and Methods

The data used for this study were obtained from a website of the Northern California Earthquakes Data Centre. The Centre is a joint project of the University of California Berkley Seismological laboratory and United States Geological Survey (USGS). It is also available in global earthquake catalogue produced from contributions of Advanced Natural Seismic Source (ANSS). The region of study is located between latitude 40° and -30° and longitude 0° and 60° . The data covers a 40-year period from 1974 to 2013 and in all, there were 58,649 earthquakes. The minimum magnitude selected in the catalog search is 0.5 and the maximum magnitude is 10.0. The minimum focal depth selected is 0.0 km while the maximum is 300 km. Each datum comprised data of occurrence of earthquake, origin time, date, magnitude, event identification and depth of earthquake. The regions studied in the African lithospheric plate were Northern Africa (latitude 20° to 40° , longitude 0° to 50°), Southern Africa (latitude -10° to -30° , longitude 20° to 40°), Eastern Africa (latitude 10° to -25° , longitude 36° to 50°) and Western Africa (latitude 0° to 7° , longitude 0° to 10°). The data for these regions were mapped out from the global seismicity map. The data were sorted out, filtered and analysed to remove errors due to

duplication and mixing of data using Compicat software. Compicat is an earthquake catalog processing software.

To study the seismic pattern or hazard of a region, there is a need to investigate seismic parameters to mitigate the future occurrence of earthquakes. (Amiri et al., 2008). Focal depth, frequency, seismic energy and epicenters relations play a paramount role in understanding seismic activity of the earth regions (Ghosh, 2007). The relationship between the size distributions of earthquakes over a large range of magnitudes in a seismogenic volume can be described by a power law equation (Abercrombie, 1995). The relationship between size distribution of earthquakes and magnitude was first discovered in 1939 in Japan and later by Gutenberg and Richter (1944) in California. One of the forms of power law is given as;

$$\text{Log}N = a + bM \dots\dots\dots 1$$

Where N is the number of earthquakes with magnitude greater than or equal to M and a and b are constants.

The parameter ‘a’ describes the productivity of a volume and ‘b’, the slope of the frequency Magnitude distribution, describes the relative size distribution of events. Parameter ‘a’ is a function of quantity of earthquakes throughout the years covered in the study area while ‘b’, in general is approximately equal to 1. Large value for b (>1) indicates predominantly small earthquakes while small values of b (<1) implies predominantly large earthquakes. The values of ‘a’ and ‘b’ were obtained from intercept and slope of the graph of Log N against M. The b-value in Gutenberg-Richter law Equation 1 is very important because it reveals a lot in the studies of seismotectonic, seismic risk analysis, prediction and hazard. Therefore, its correct computation represents an important challenge and gives vital information as per seismology of a given area.

In order to investigate the earthquake distribution patterns in the study area, the earthquake focal depths were plotted against the Longitude and Latitude parameters of earthquake epicenters.

The frequencies of earthquakes were obtained and plotted against earthquake epicenters in order to investigate the frequency distribution of the earthquake along the epicenters in the regions of study.

The weighted sums of seismic energy were obtained for each region of study and correlated with the latitudinal and longitudinal earthquake epicenters to investigate the seismotectonic activities of the African plate.

3.0 DISCUSSION

The Gutenberg – Richter relation for the whole region of African plate gives values of 6.68 and 0.904 as “a” and ‘b’ values respectively as shown in figure 4. The parameter ‘a’ value characterized the general level of seismicity in the whole African lithospheric plate. This value (greater than 1) indicates that the earthquake productivity in the region, in terms of quantity is significant. The b value (less than 1) signifies that there are many intermediate earthquakes than smaller ones in the region. The distribution of smaller and intermediate earthquakes is almost equal and the ratio is slightly below unity. The a and b values obtained from the Gutenberg – Richter relation for Northern Africa, Eastern Africa, Southern Africa and Western Africa portions of African plate were: a = 6.796, b = 0.923, a = 2.014, b = 0.213, a = 2.0, b = 0.309 and a = 0.7, b = 1.0652 as shown in figures 5, 6, 7 and 8 respectively. Interpretation of these values is that the Northern, Southern and Eastern regions of Africa are more prone to a significant level of seismic hazard than the West Africa region. Thus, they are regarded as aseismic zones of the African plate. This is connected to the ‘a’ value (greater than 1) obtained for the three regions. The higher the ‘a’ value obtained for a region, the more the earthquake occurrence in that region.

140 Thus the level of seismicity is highest in the Northern region owing to its highest value of 'a'.
141 The rate of earthquake occurrence in the West Africa region is low due to its lowest value of 'a' (
142 less than 1) obtained for the region. This implies that the region is aseismic zone of the Africa
143 plate. However in the West African sub regions, there had been some recorded cases of
144 spectacular and disastrous earthquakes. For example, the December 1983 Guinea earthquake
145 which claimed 300 lives and injured 10,000 more. In 1983, a 6.5 magnitude earthquakes hit
146 Ghana and many people were killed with severe damage to properties. Other tremors in this
147 region include 21st December 1963 Ijebu-Ode tremor with intensity 5.0 richter scale, 1st July
148 1975 tremor near Gary in Dambata, Kano and Yola tremor of 8th December 1984, Ibadan tremor
149 of 2001 all in Nigeria. Therefore this does not means that the region is free from earthquake
150 occurrence.

151 The analysis of longitudinal and latitudinal (epicenters) with frequency of earthquakes, weighted
152 sum of seismic energy and focal depths, as shown in figures 9 – 28, indicated that the seismicity
153 of Africa is mainly concentrated in two main regions - Northern and South-eastern Africa. This
154 implied that the seismotectonic process is marked by a relative motion alternating between left
155 and right lateral along the African and Eurasian plate. The south-eastern African region covers a
156 region which is prone to a significant level of seismic hazard due to the presence of the East
157 African rift system. The whole region is crossed by a tectonically active rift system within a
158 stable African shield known as the East African Rift System (EARS). The east African Rift
159 trends largely north south. The west Africa experienced less seismicity. The peak values of focal
160 depths, seismic energy and frequency of earthquakes varied with the earthquake epicenters. The
161 intermediate focal depths, large seismic energy are very predominant in the Northern Africa. The

162 highest frequency of earthquakes features in the Northern and Southeastern Africa. This is in
163 consonance with the 'a' and 'b' value results.

164 The patterns of earthquakes are sparse in Eastern African. This may be due to the East African
165 Rift System. The frequency of earthquakes is lowest in the Western and Southern African. Also
166 the weighted sum of seismic energy along the epicenters is minimal with the predominant
167 shallow focal depth. This implies that there are more shallow earthquakes than intermediate
168 earthquakes in the regions.

169 170 **4.0 CONCLUSION**

171
172 The Northern and Eastern regions of the African plate are more prone to earthquake hazards.
173 The earthquake clusters at the Northern Africa area and is dispersed at other regions of the
174 African plate. Both shallow and intermediate focal depths occur in the African plate, but the
175 immediate focal depths are notable in the northern and eastern part of Africa.
176 Earthquakes occurring in the African lithospheric plate concentrate mainly in the northern and
177 eastern region. Tectonic stress is very low in the southern and western Africa regions but higher
178 in northern and eastern Africa part. Increase in seismic energy is predominant in both northern
179 and eastern Africa.

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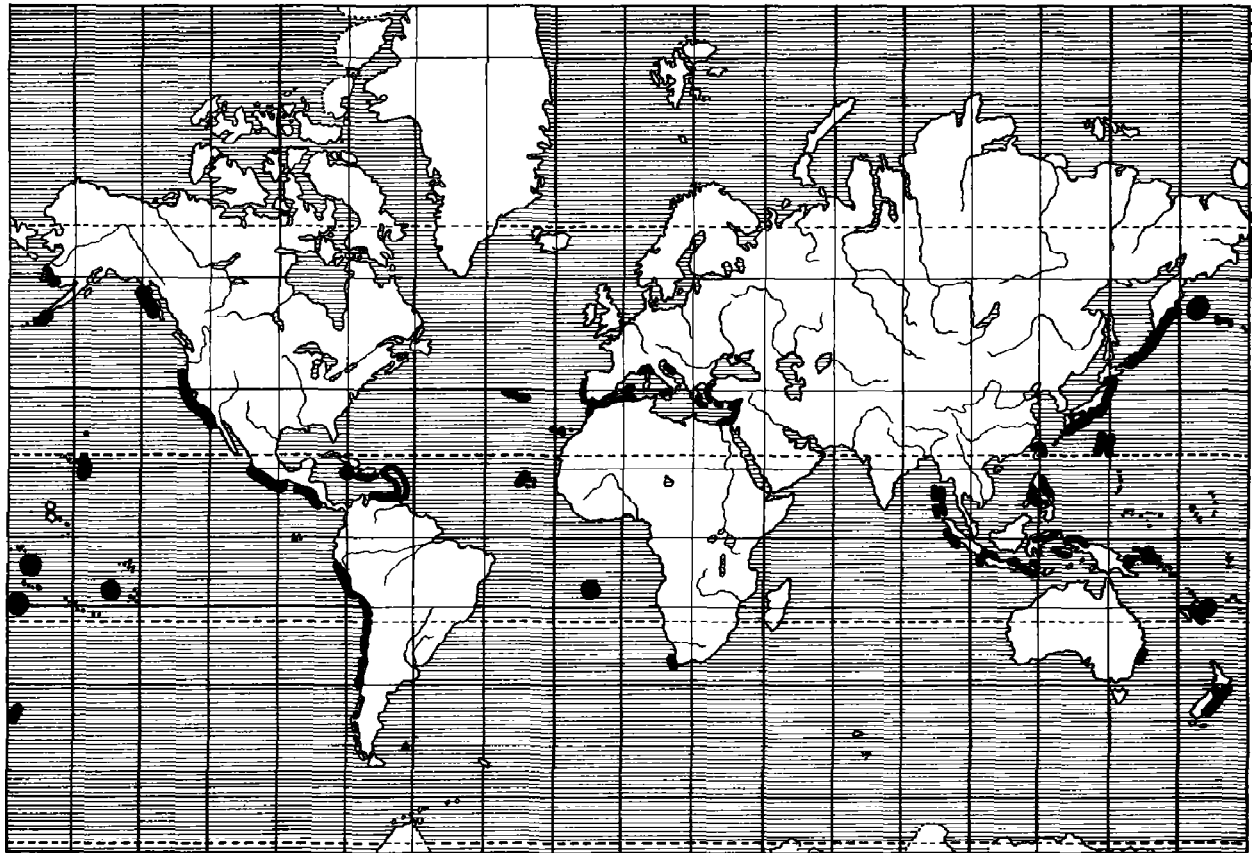


Figure 1: Map of seismicity throughout the world compiled by Rudolf (adapted from UNESCO survey of the natural resources of African continent)

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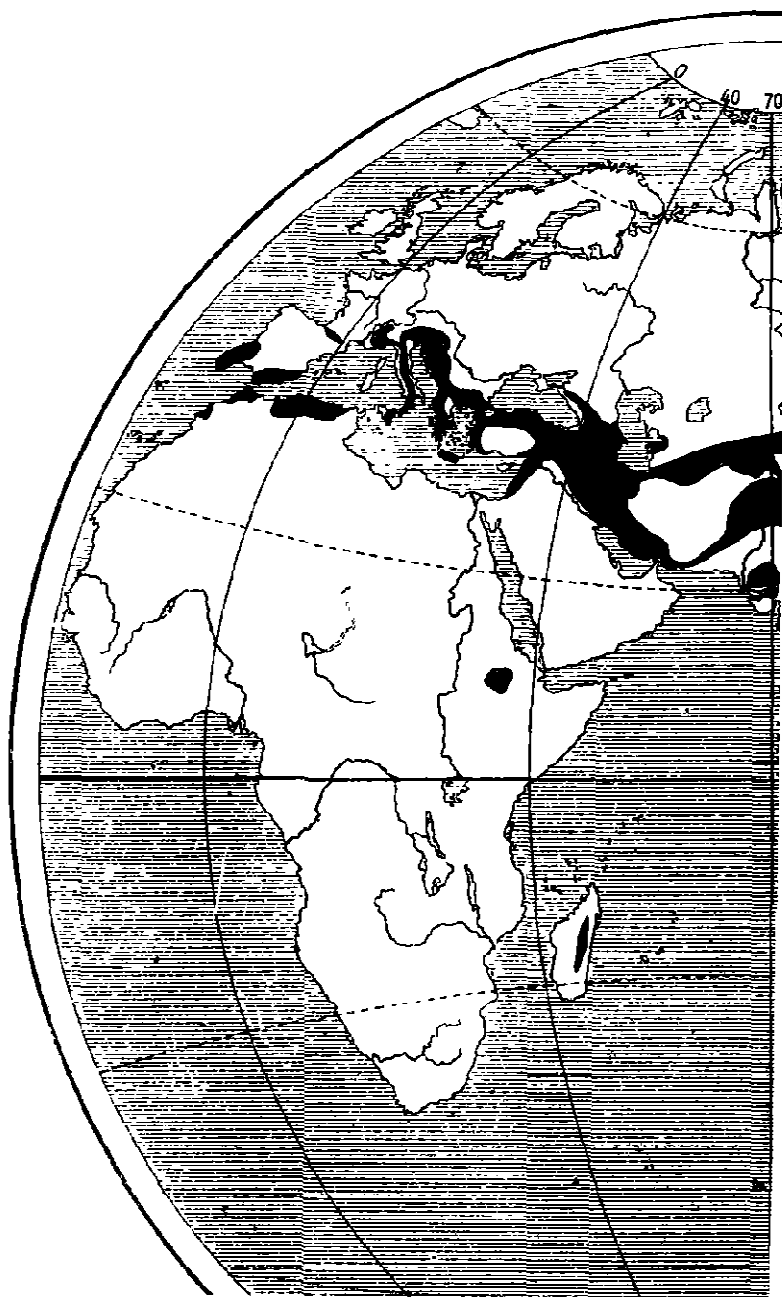


Figure 2: Map of seismicity throughout the world compiled by Montessus de Ballore (adapted from UNESCO survey of the natural resources of African continent)

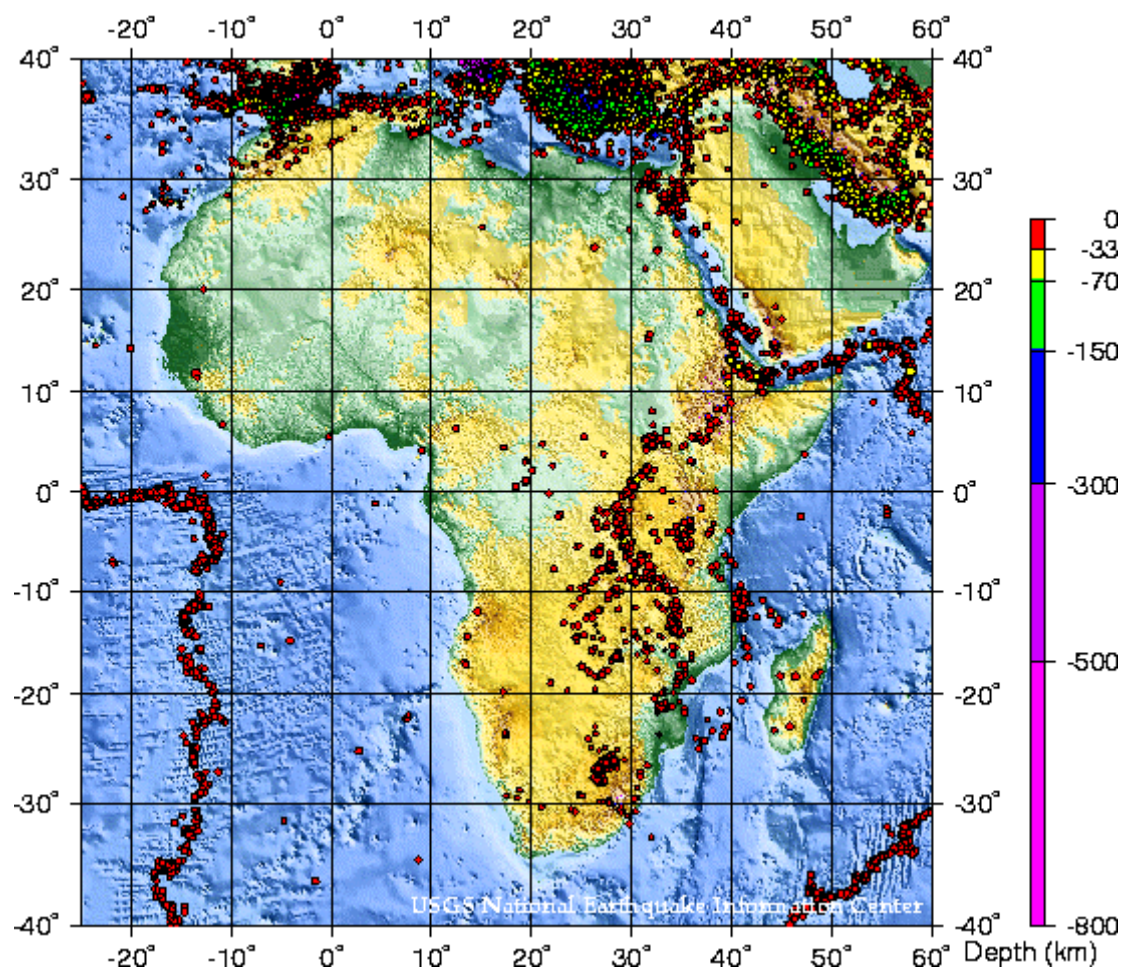


Figure 3: A Map showing seismicity of Africa (adapted from USGS National Earthquake information center)

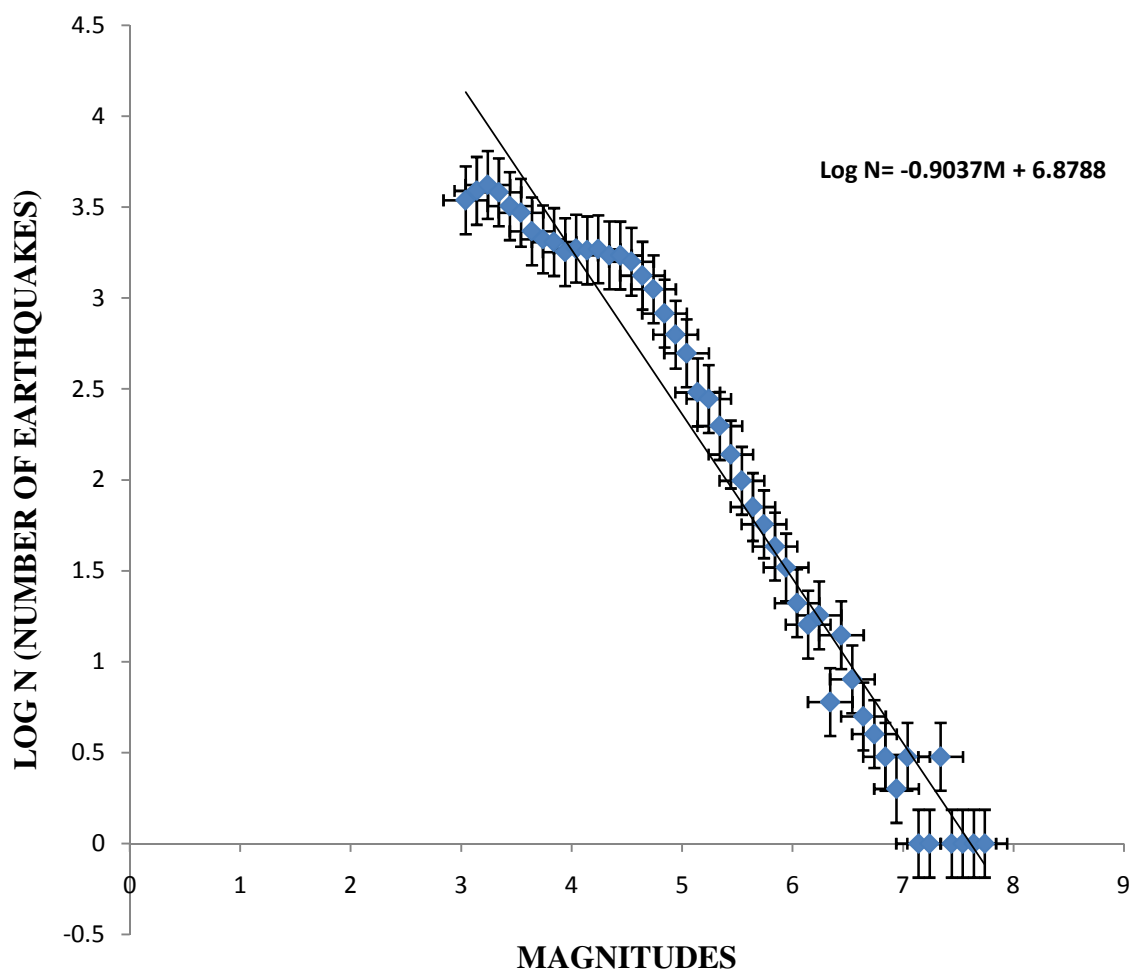


Figure 4: The Gutenberg – Richter Relation for the African plate seismicity

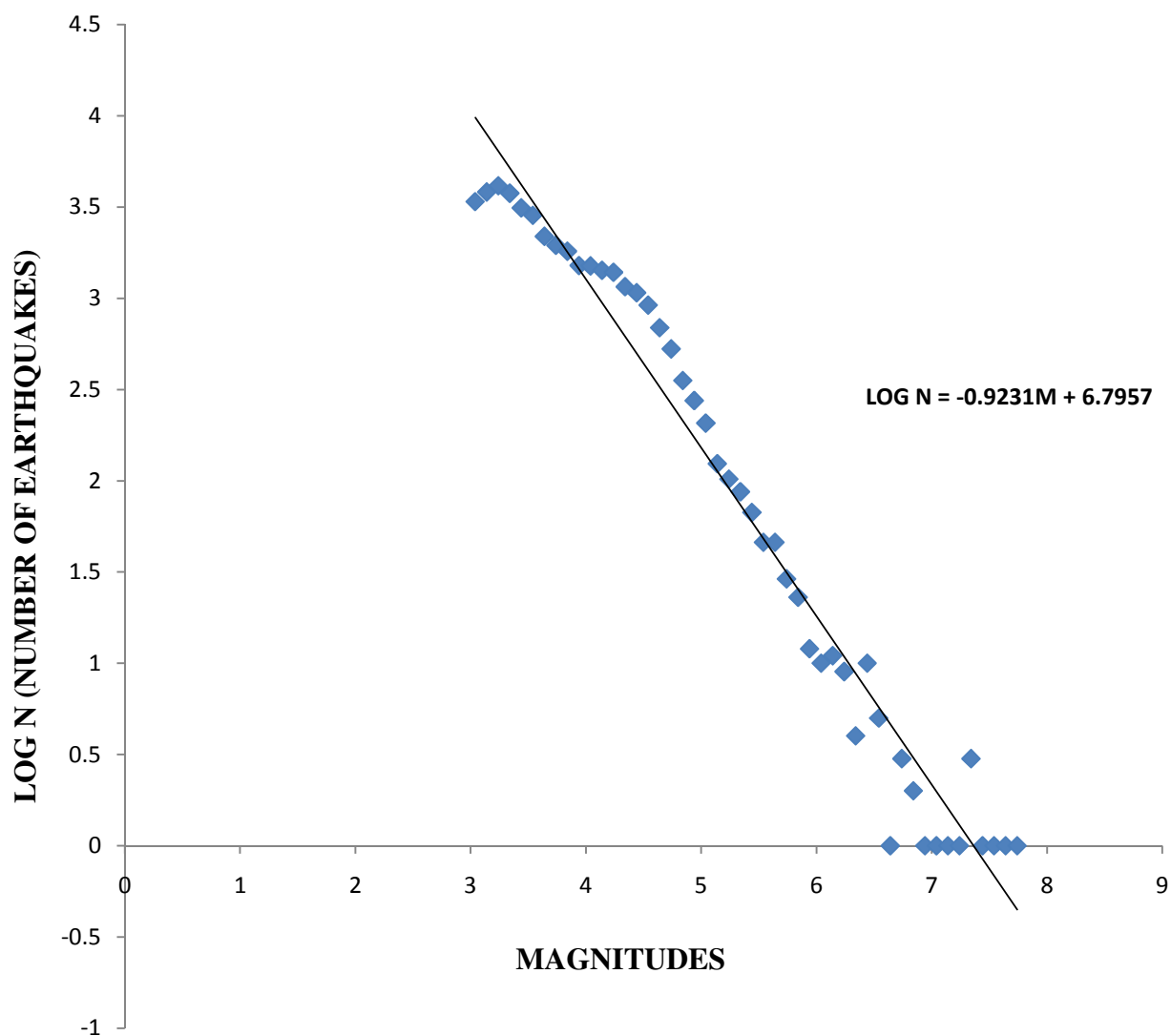
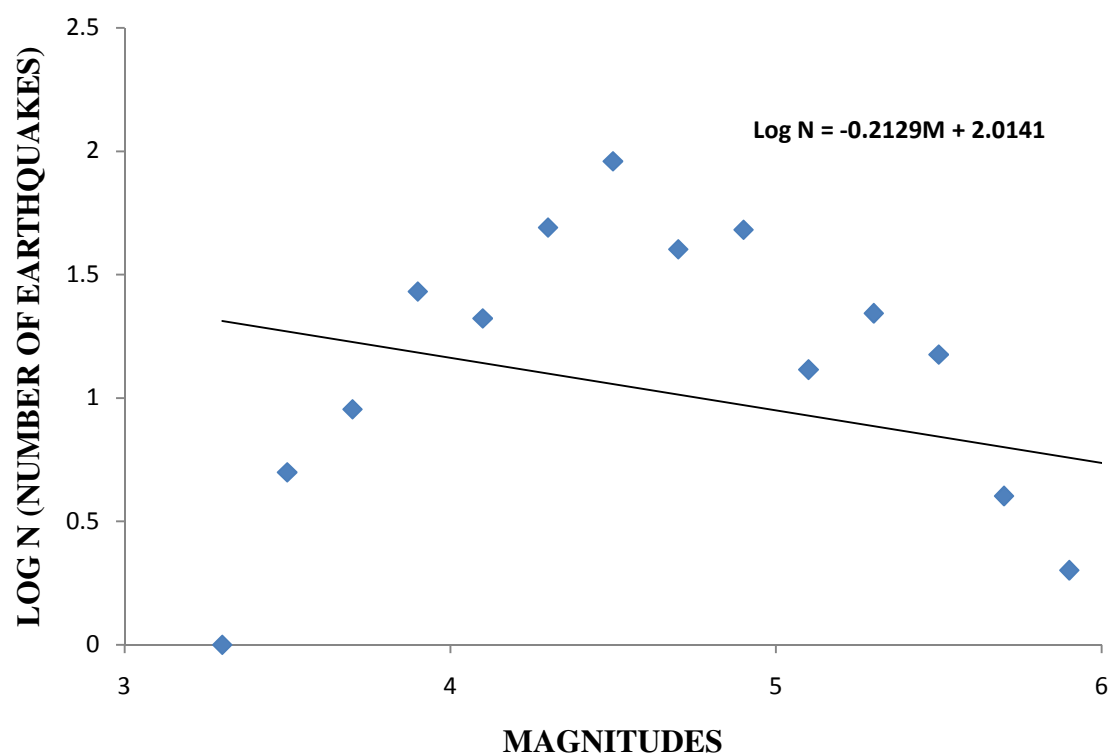


Figure 5: The Gutenberg – Richter Relation for the Northern Africa seismicity

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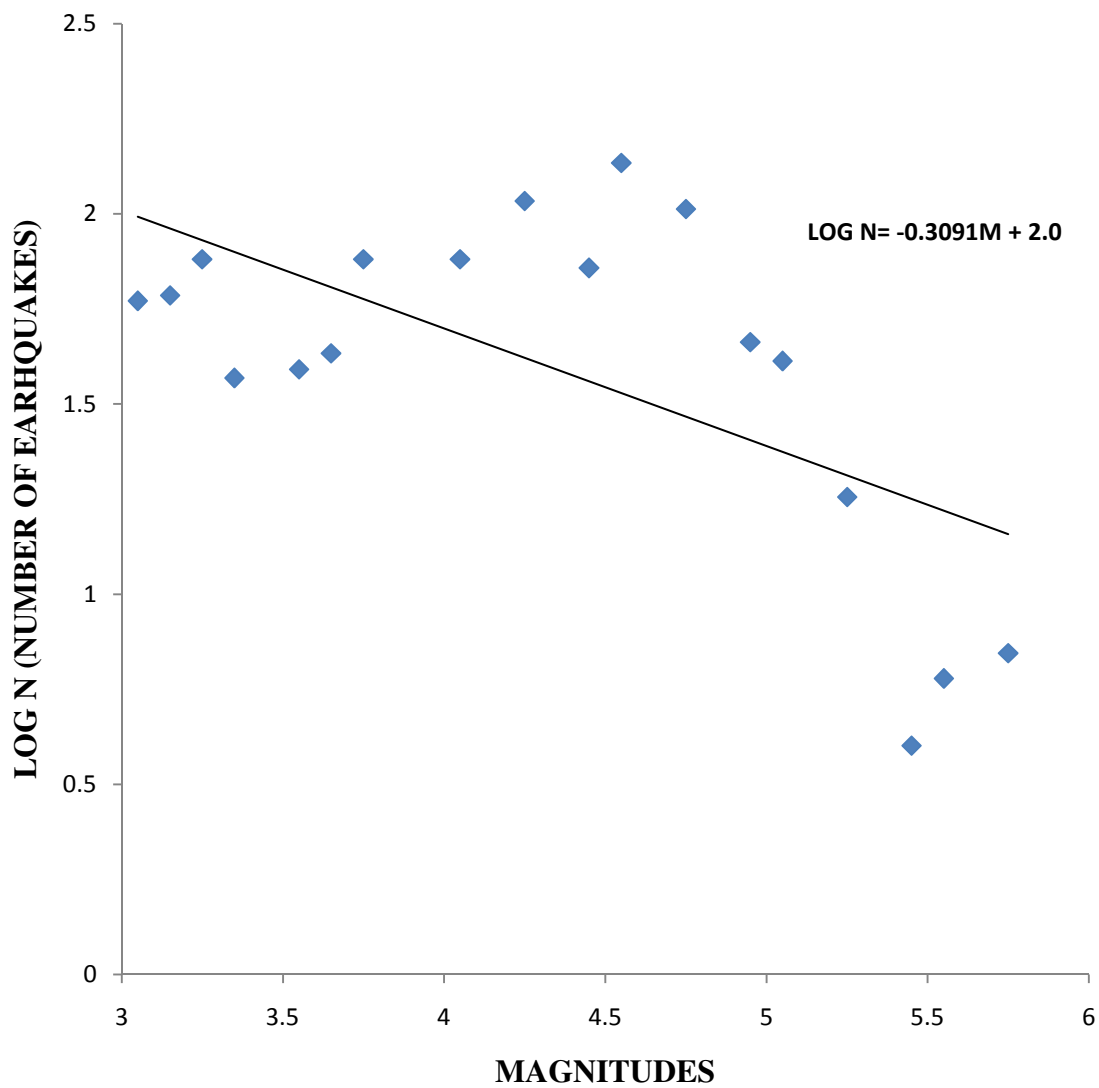
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285 **Figure 6: The Gutenberg – Richter Relation for the Eastern Africa seismicity**

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290 **Figure 7: The Gutenberg – Richter Relation for the Southern Africa seismicity**

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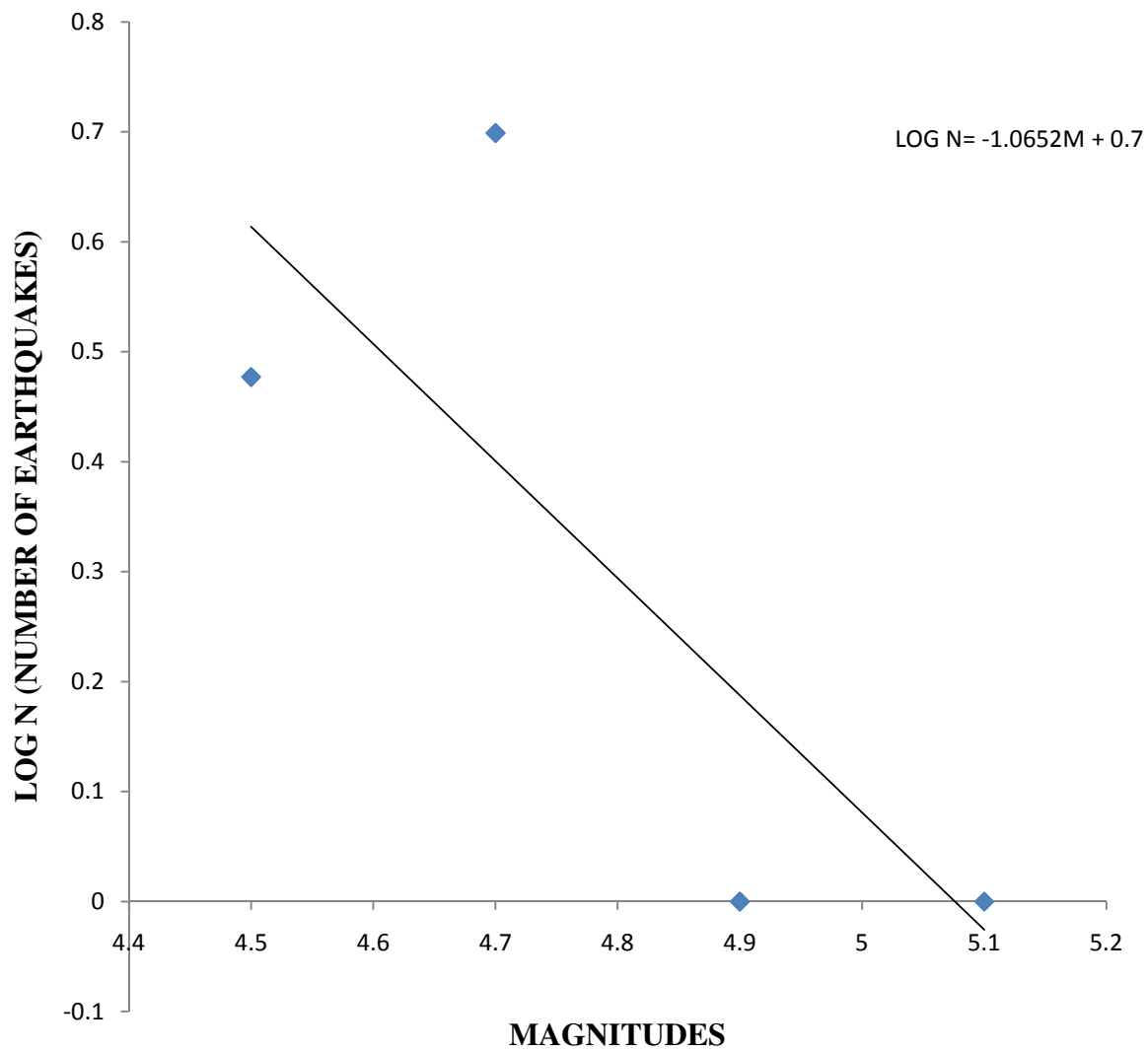


Figure 8: The Gutenberg – Richter Relation for the Western Africa seismicity

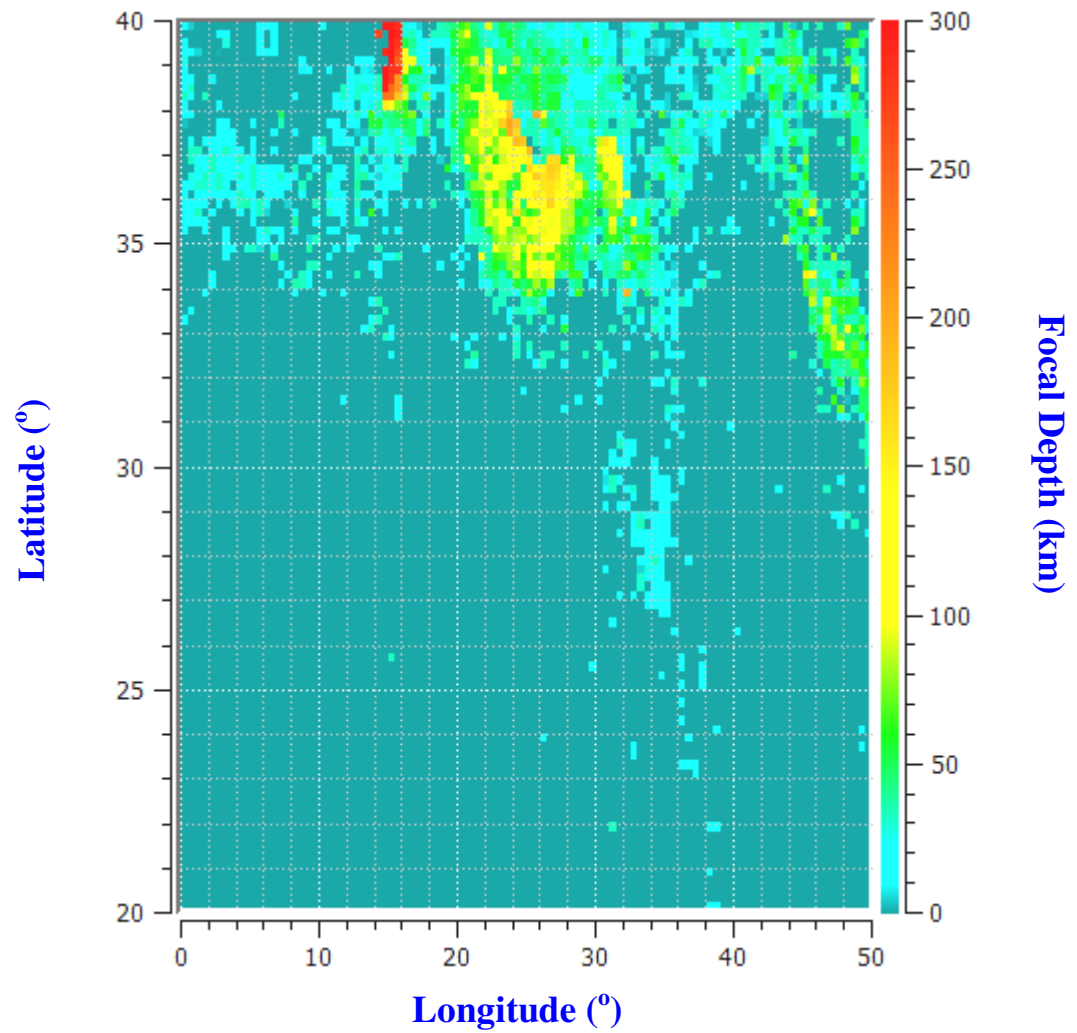


Figure 9: Focal Depth against Latitude and Longitude of Earthquakes in Northern Africa 1974 – 2013

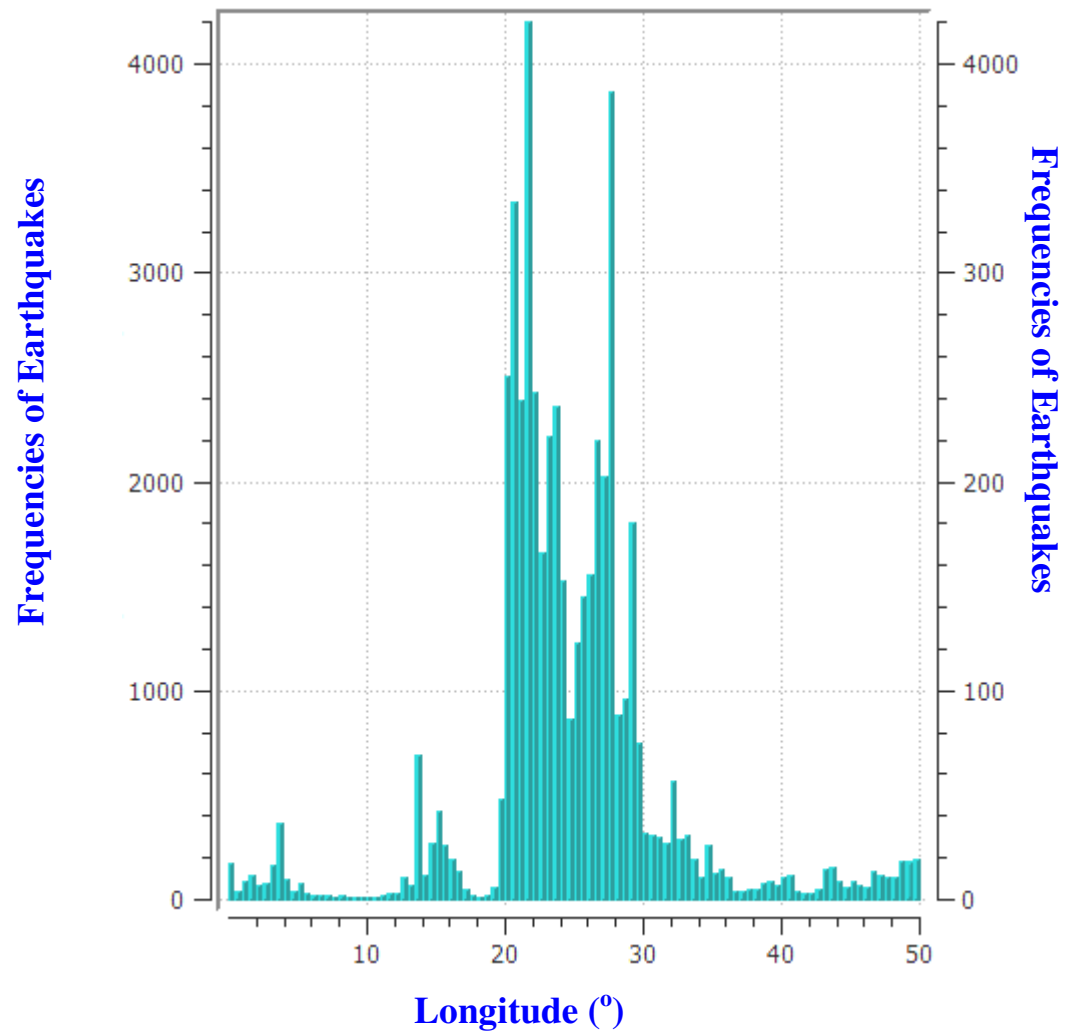


Figure 10: Frequency Against Longitude of Earthquakes in Northern Africa 1974 – 2013

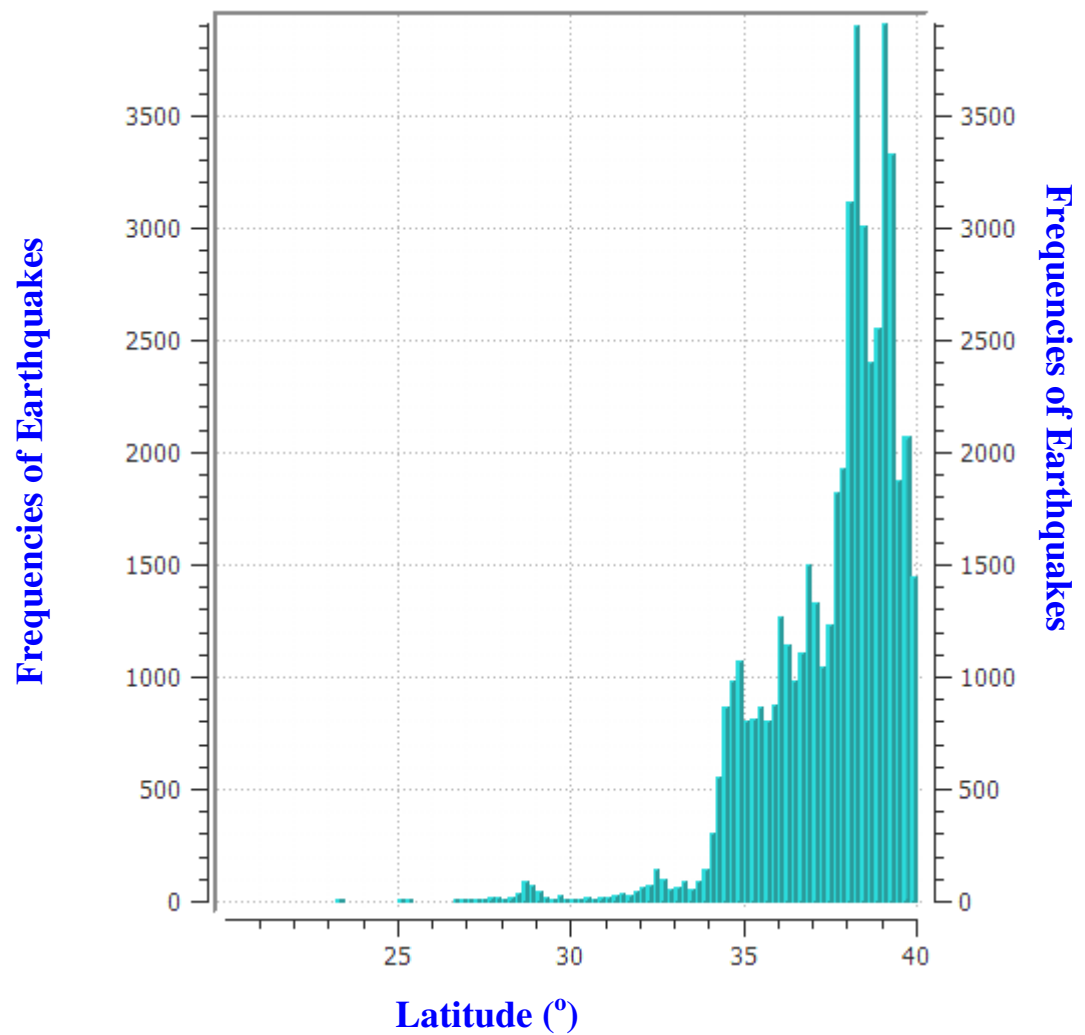
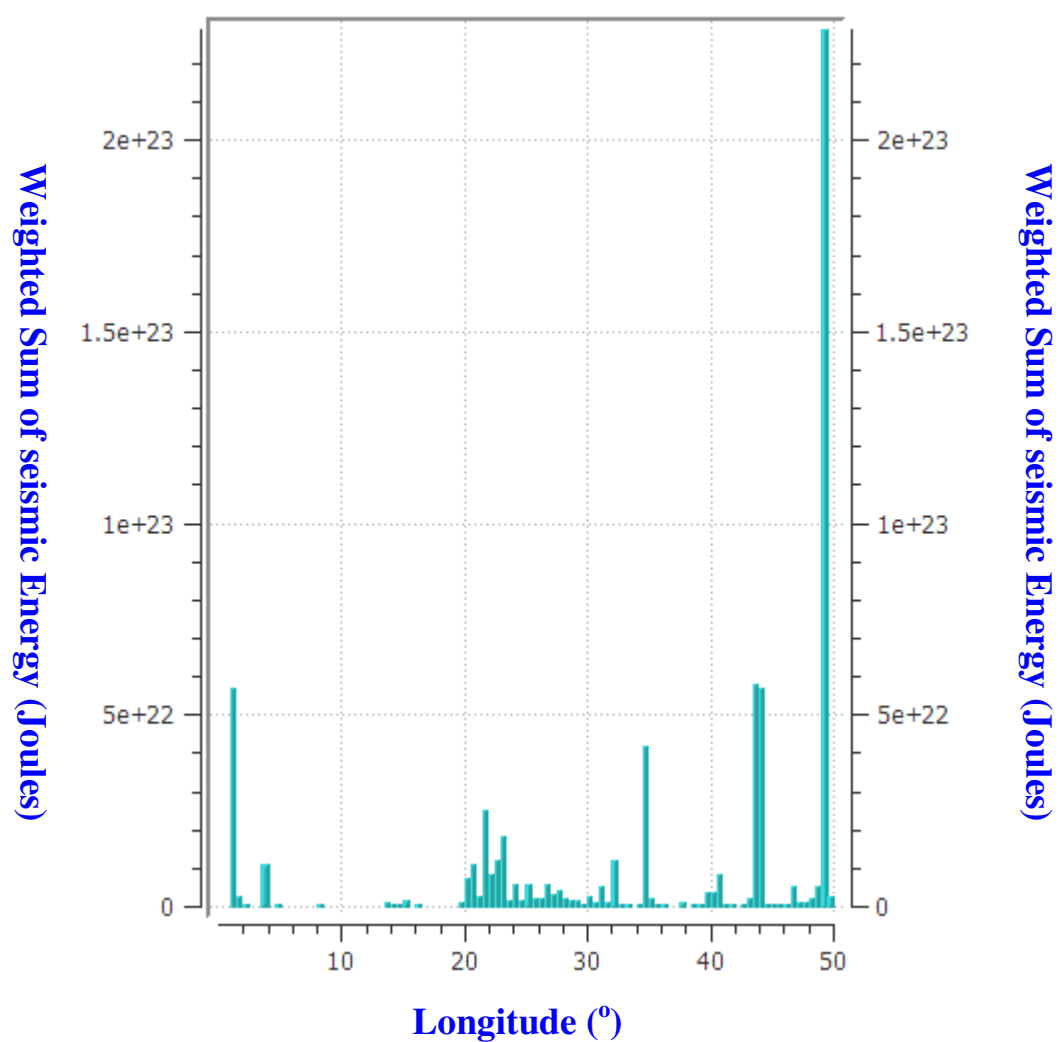


Figure 11: Frequency Against Latitude of Earthquakes in Northern Africa 1974 – 2013

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Figure 12: Weighted Sum of Seismic Energy Against Longitude of Earthquakes in Northern Africa 1974 – 2013

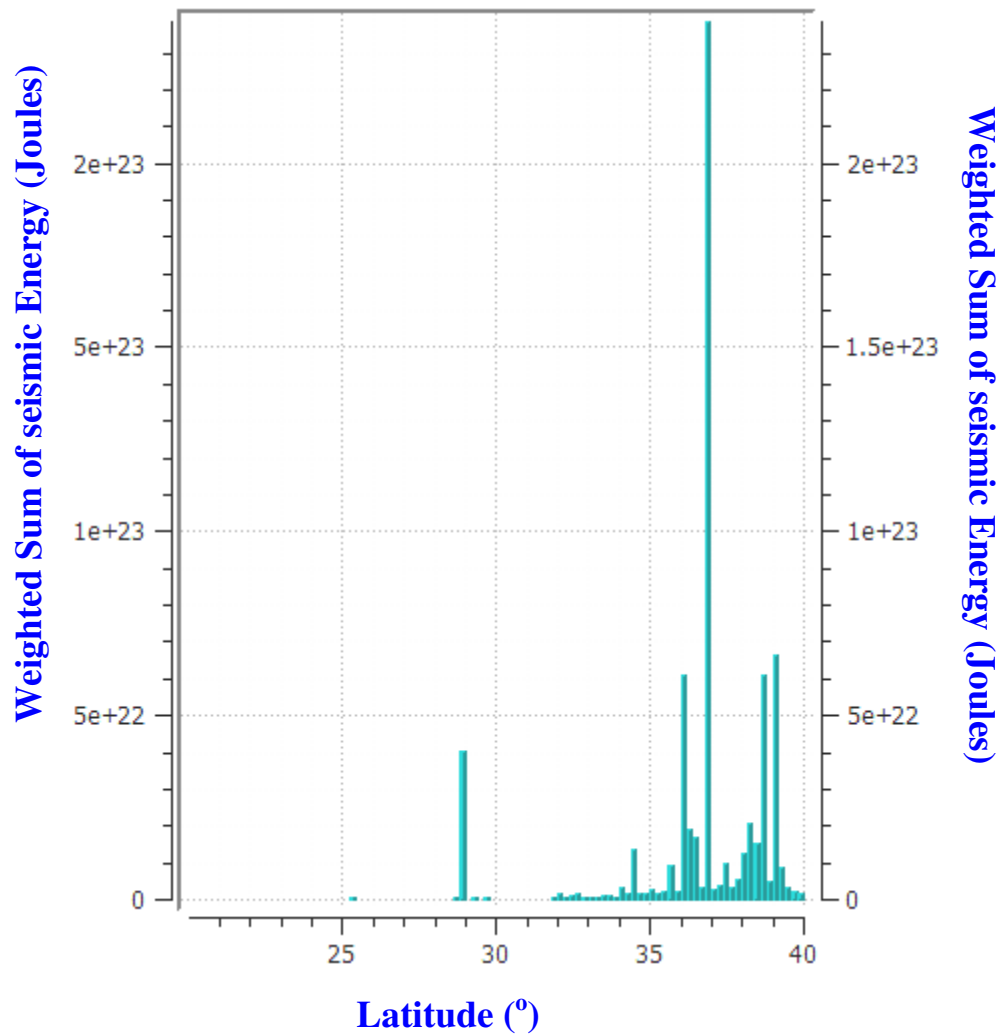


Figure 13: Weighted Sum of Seismic Energy Against Latitude of Earthquakes in Northern Africa 1974 – 2013

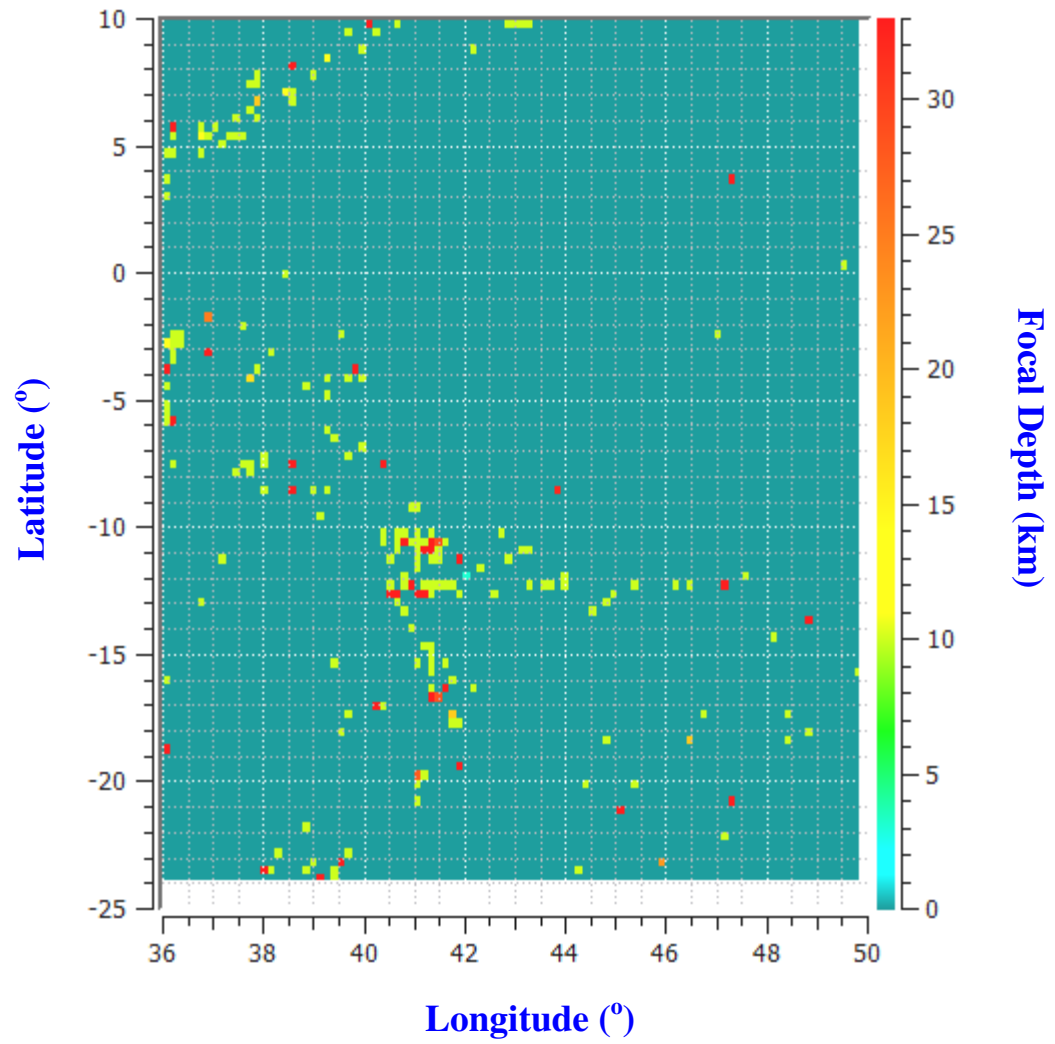


**Figure 14: Focal Depth Against Latitude And Longitude of Earthquakes in Eastern Africa
1974 – 2013**

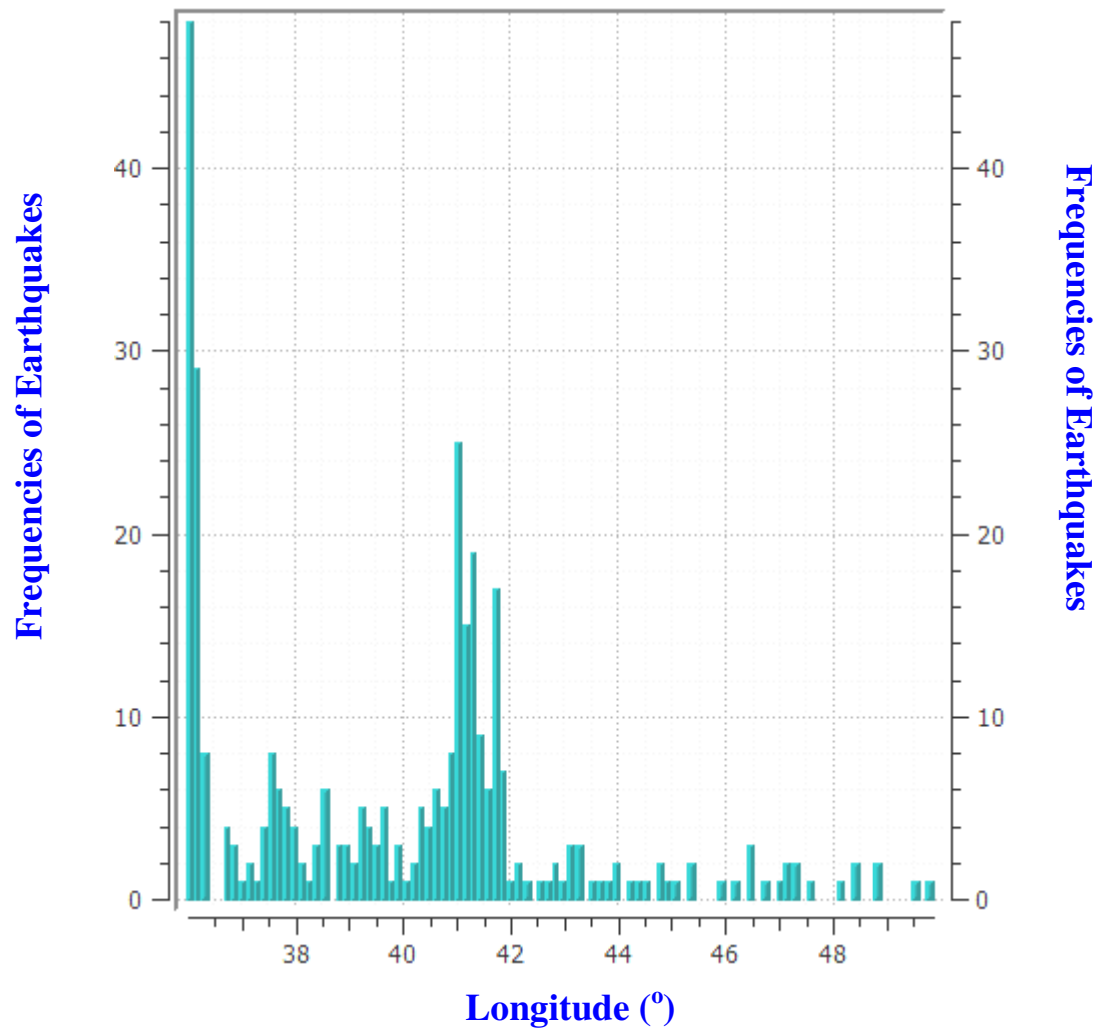


Figure 15: Frequency Against Longitude of Earthquakes in Eastern Africa 1974 – 2013

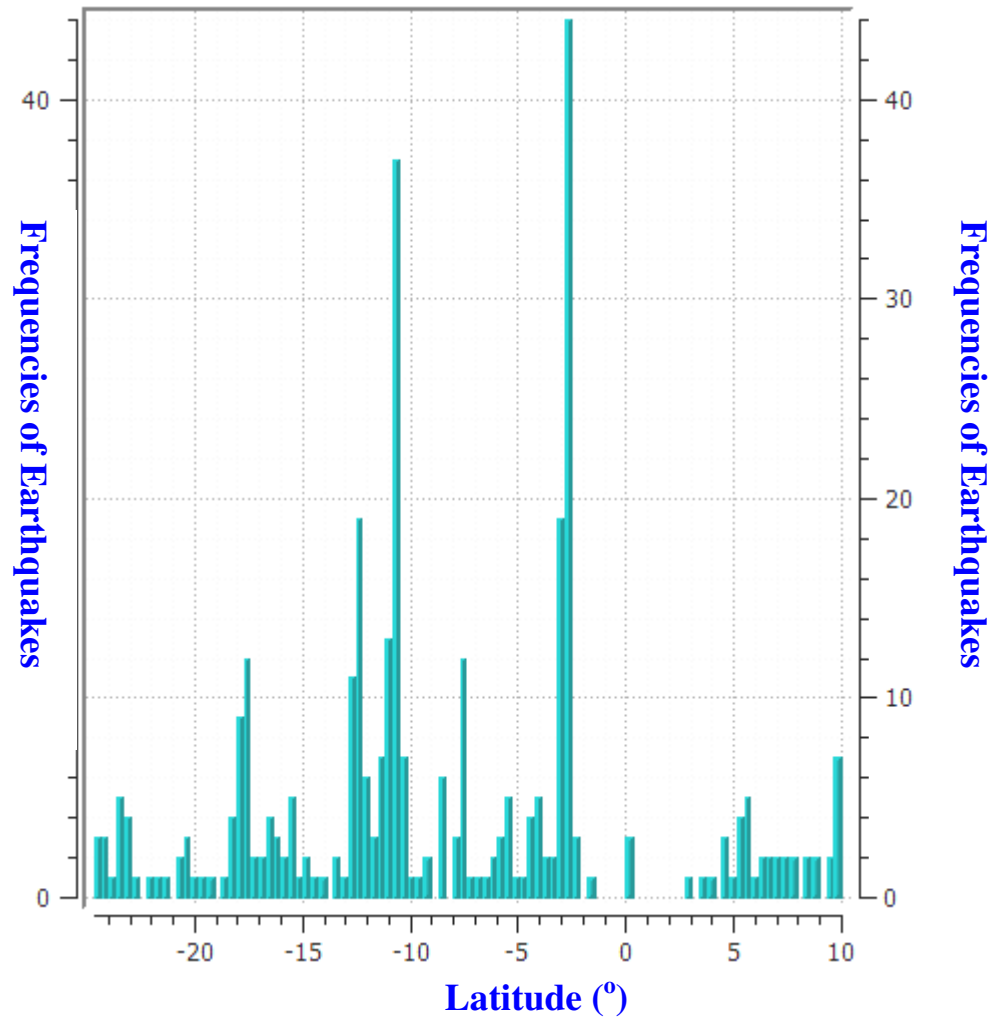


Figure 16: Frequency Against Latitude of Earthquakes in Eastern Africa 1974 – 2013

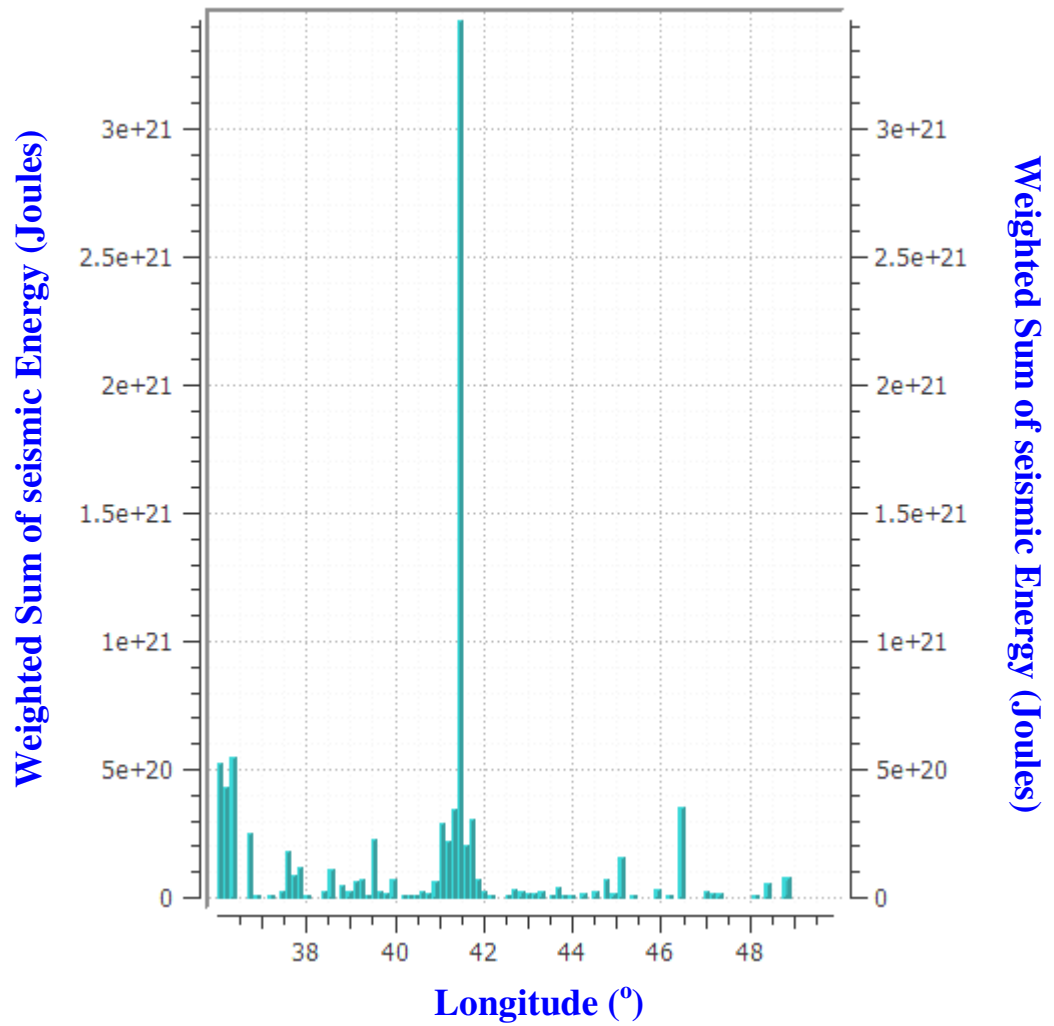


Figure 17: Weighted Sum of Seismic Energy Against Longitude of Earthquakes in Eastern Africa 1974 – 2013

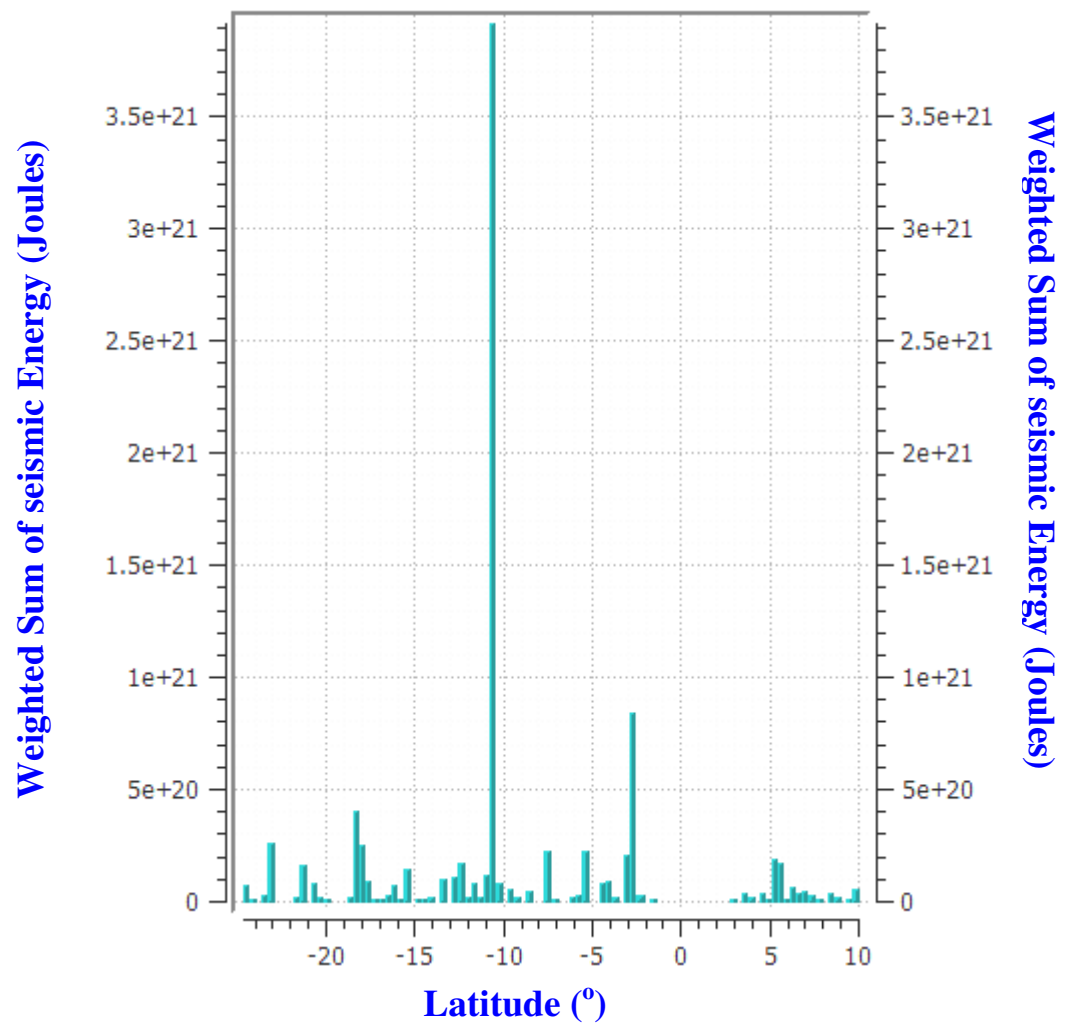


Figure 18: Weighted Sum of Seismic Energy Against Latitude of Earthquakes in Eastern Africa 1974 – 2013

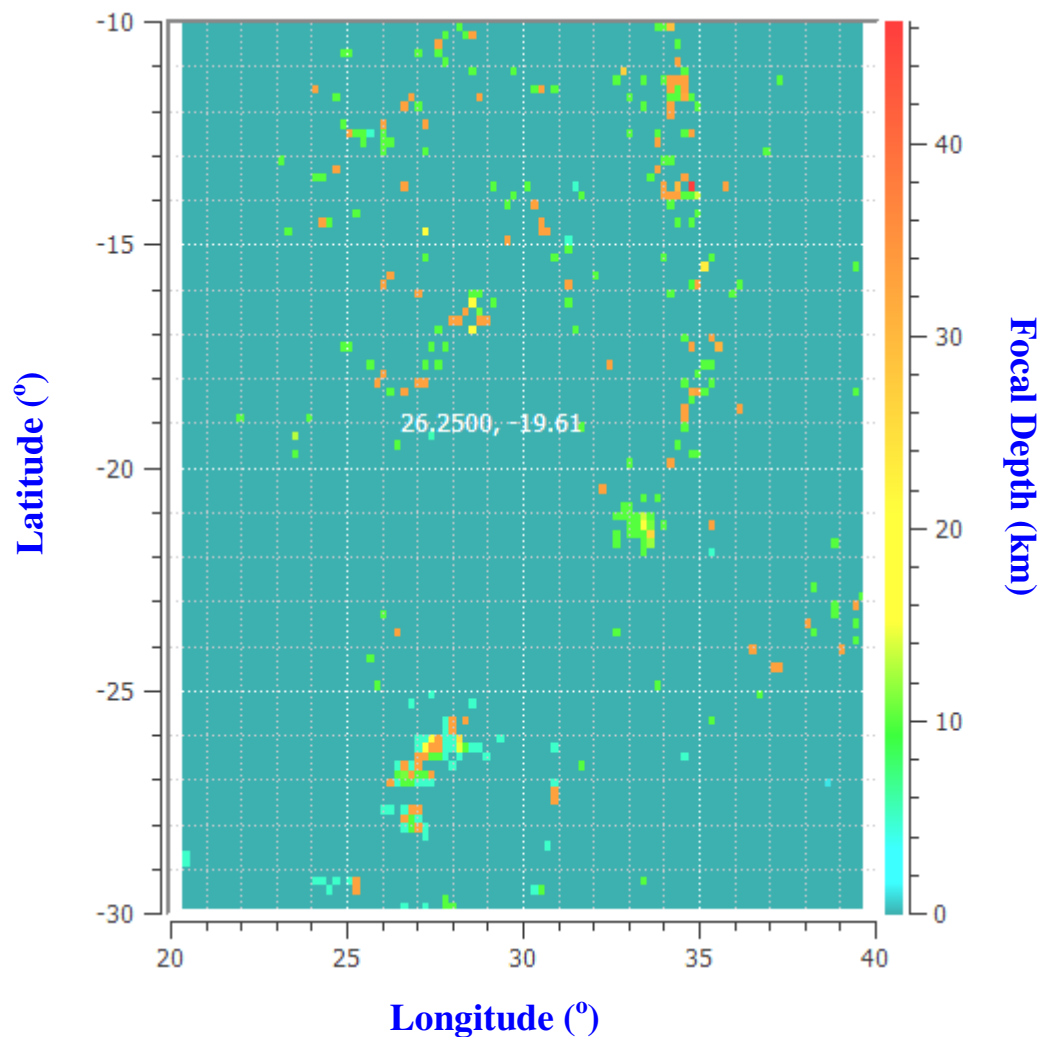


Figure 19: Focal Depth against Latitude and Longitude of Earthquakes in Southern Africa 1974 – 2013

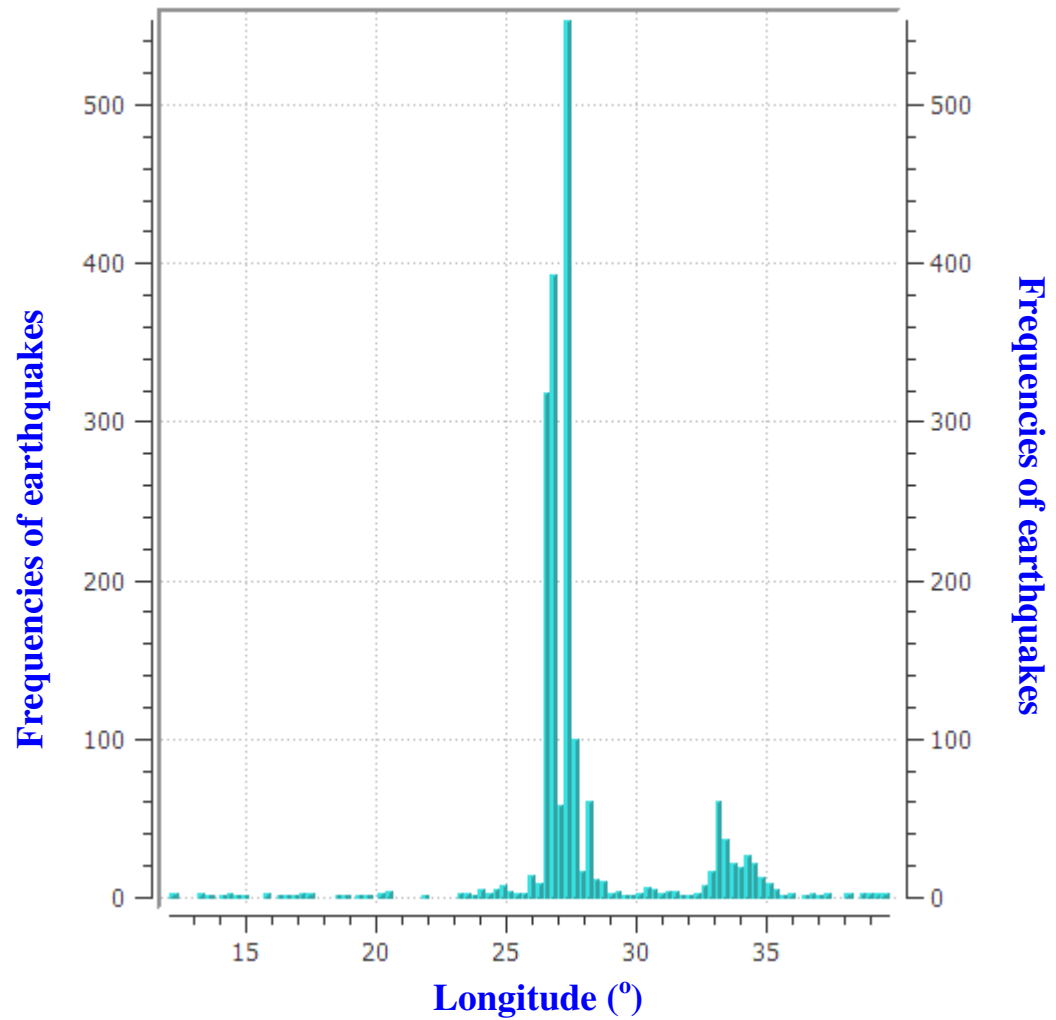


**Figure 20: Frequency Against Longitude of Earthquakes in Southern Africa
1974 – 2013**

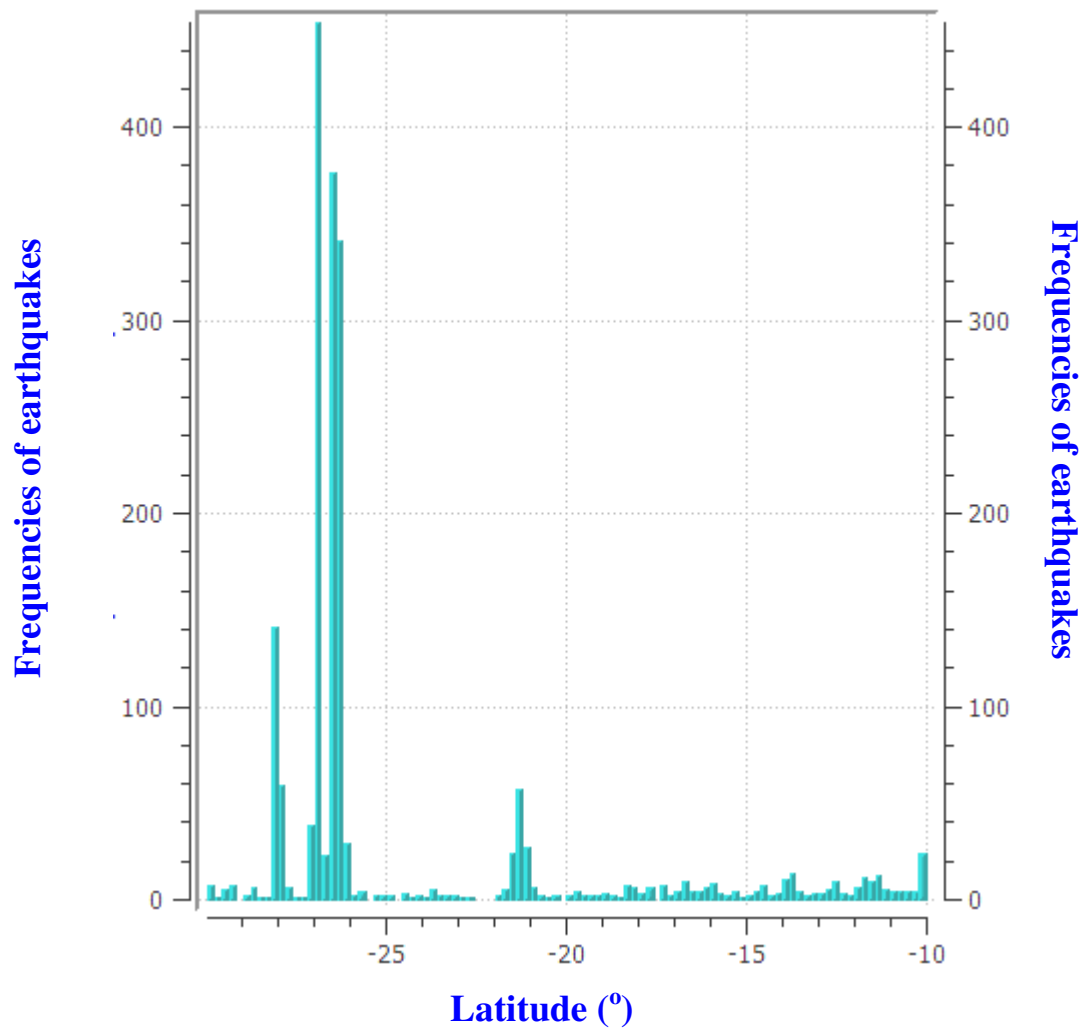


Figure 21: Frequency Against Latitude of Earthquakes in Southern Africa 1974 – 2013

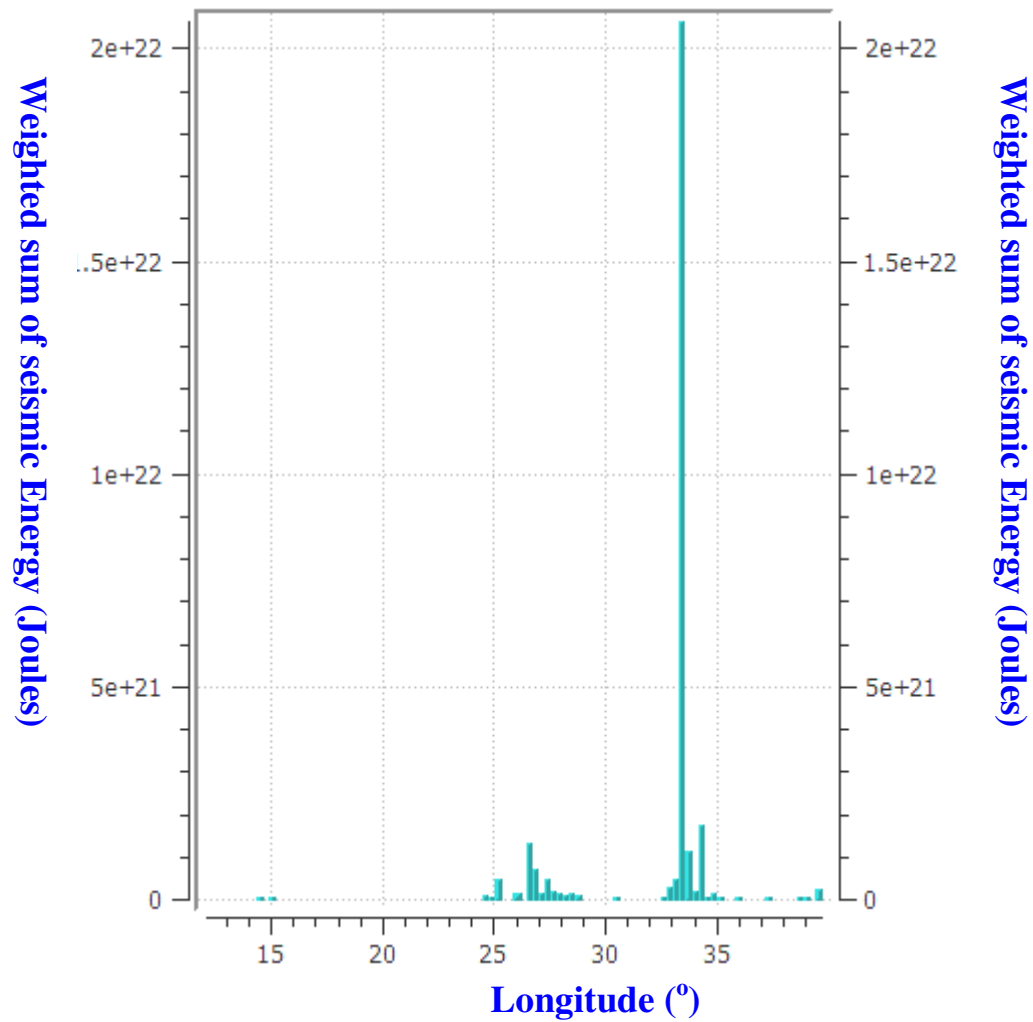


Figure 22: Weighted Sum of Seismic Energy Against Longitude of Earthquakes in Southern Africa 1974 – 2013

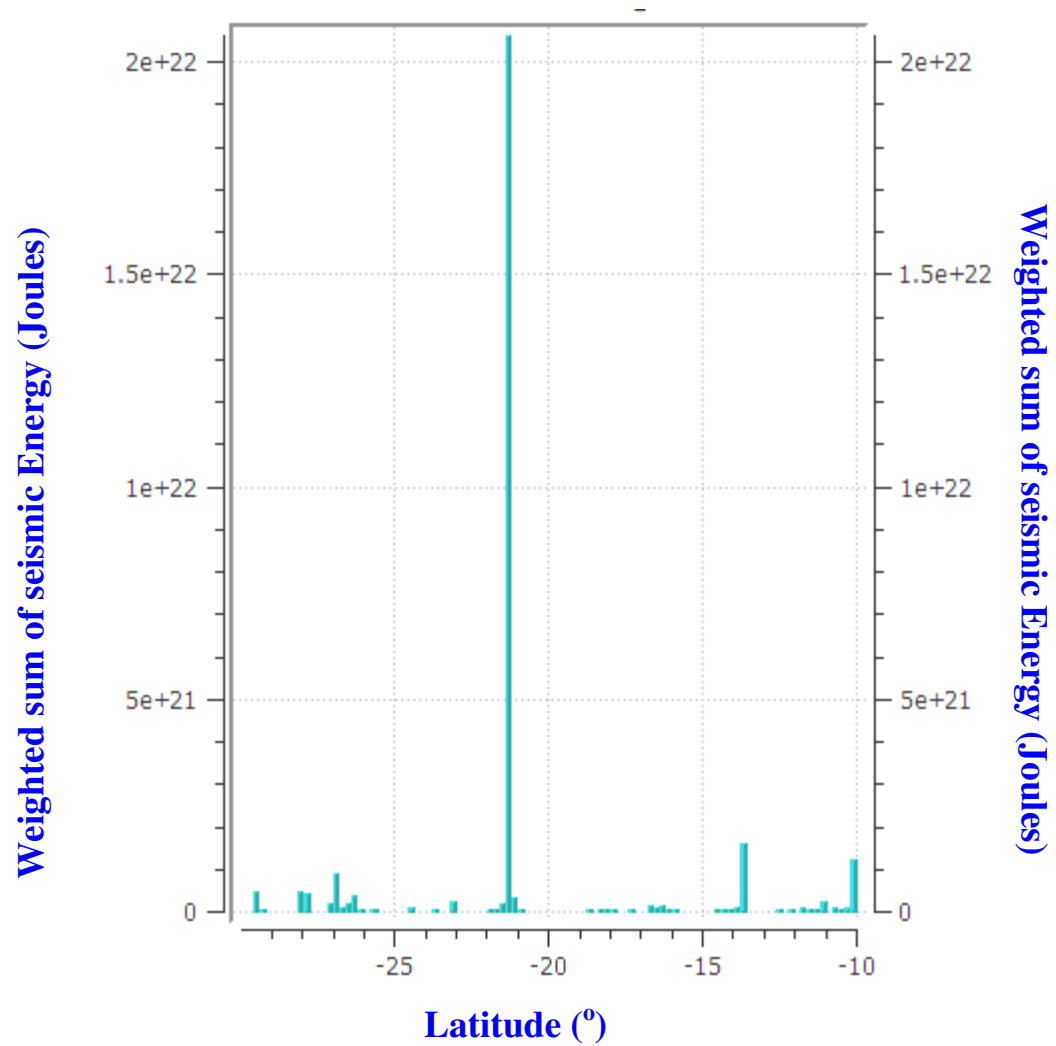


Figure 23: Weighted Sum of Seismic Energy Against Latitude of Earthquakes in Southern Africa 1974 – 2013

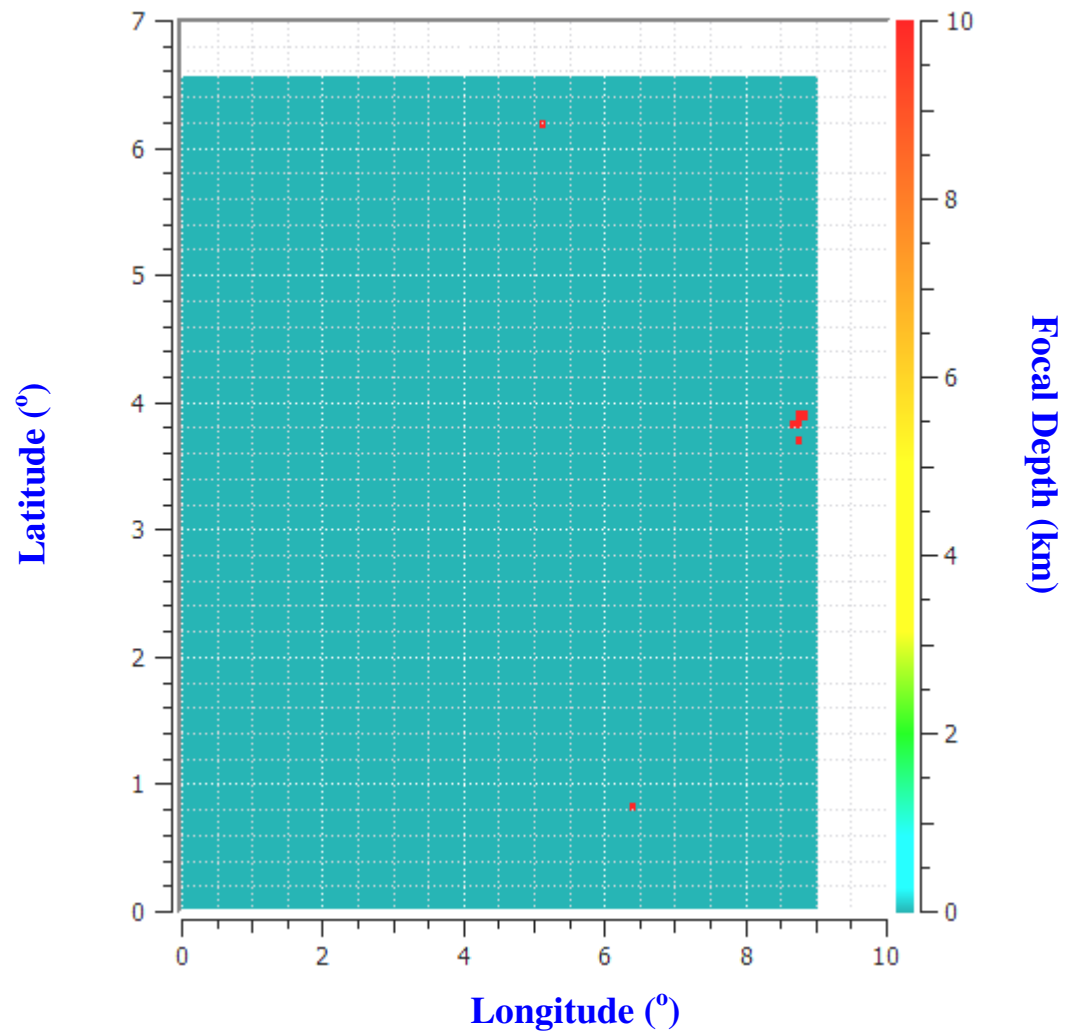


**Figure 24: Focal Depth Against Latitude And Longitude of Earthquakes in Western Africa
1974 – 2013**

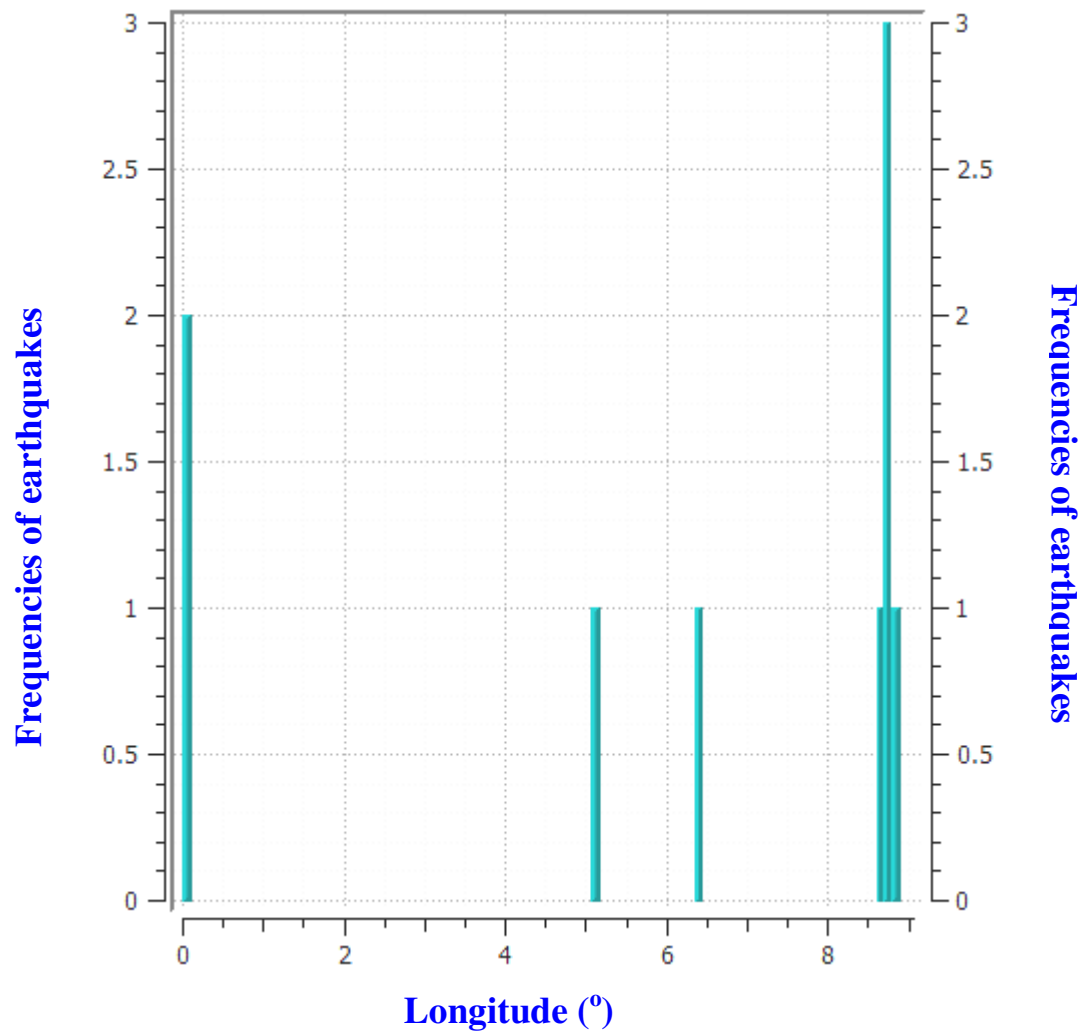


Figure 25: Frequency Against Longitude of Earthquakes in Western Africa 1974 – 2013

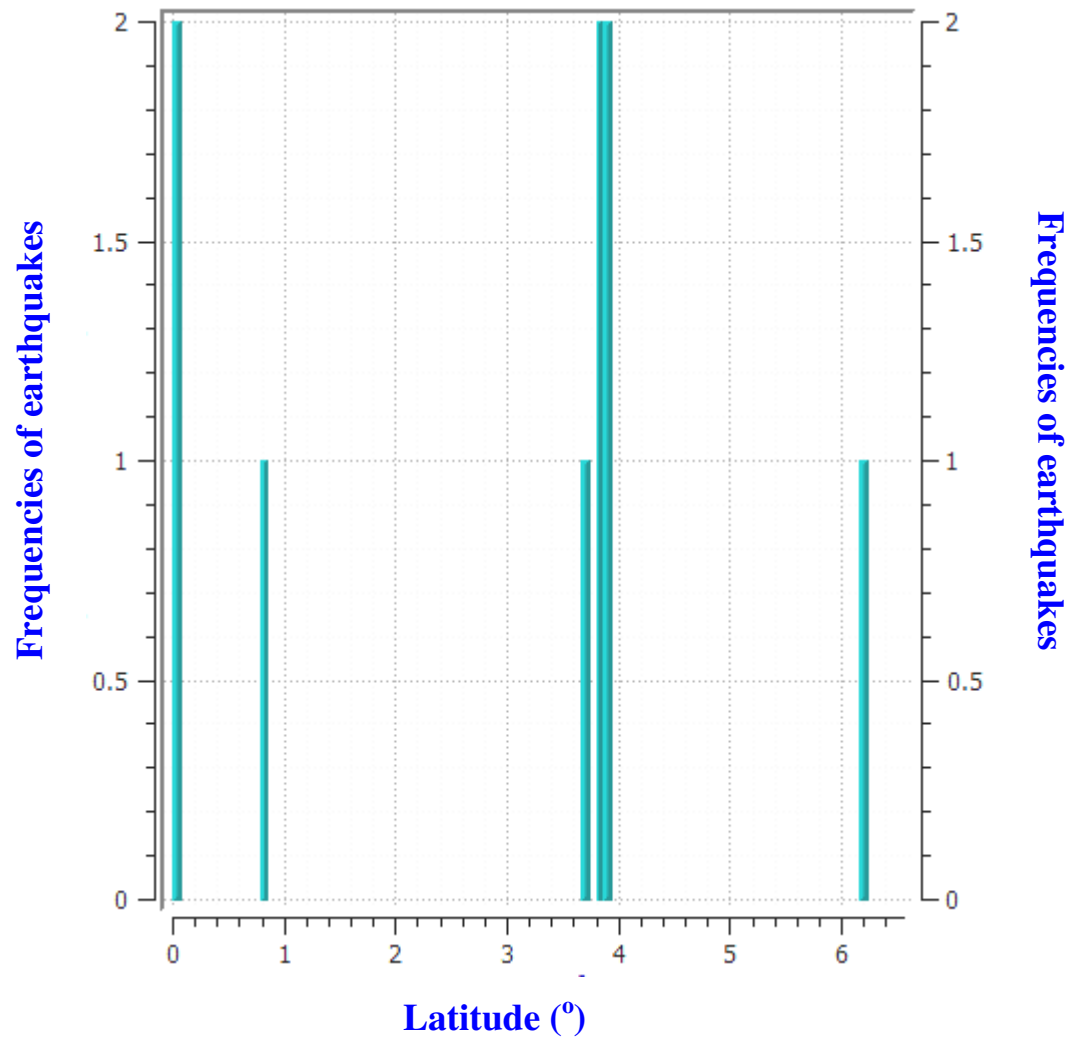


Figure 26: Frequency Against Latitude of Earthquakes in Western Africa 1974 – 2013

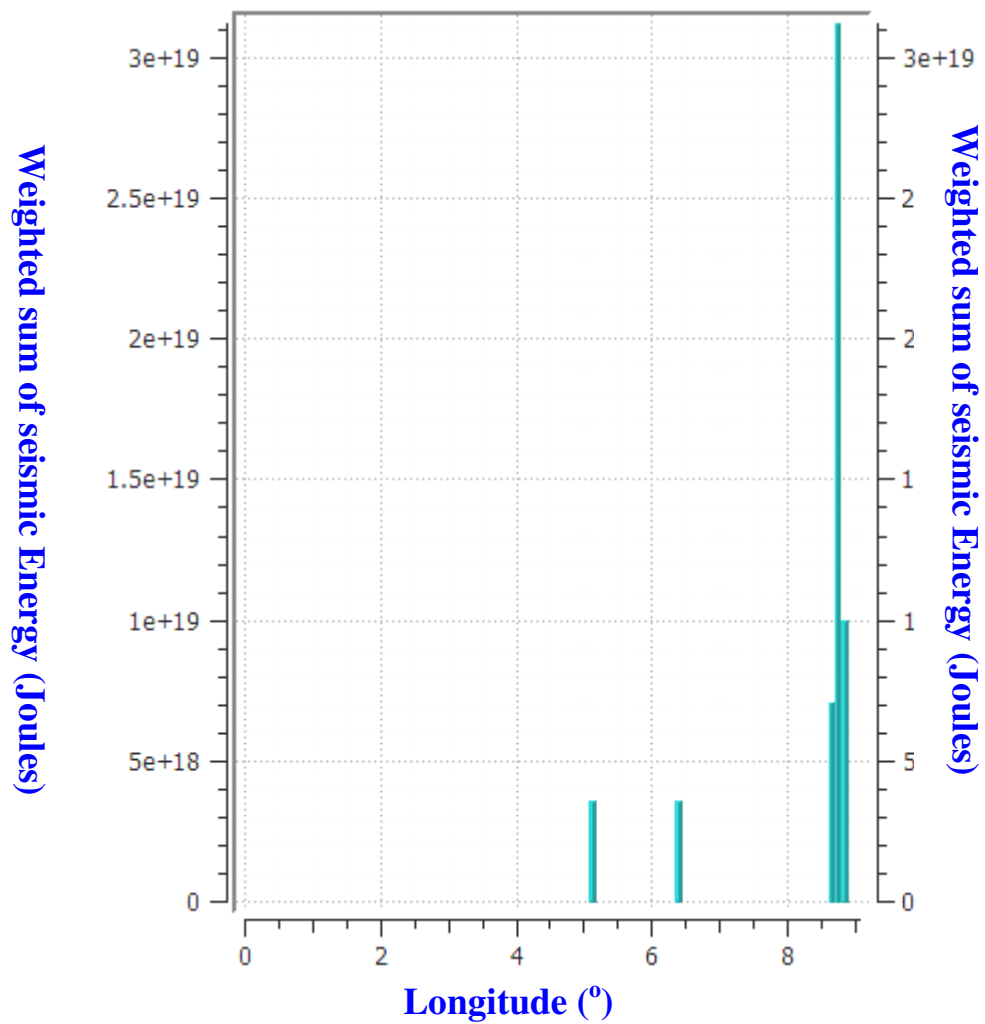


Figure 27: Weighted Sum of Seismic Energy Against Longitude of Earthquakes In Western Africa 1974 – 2013

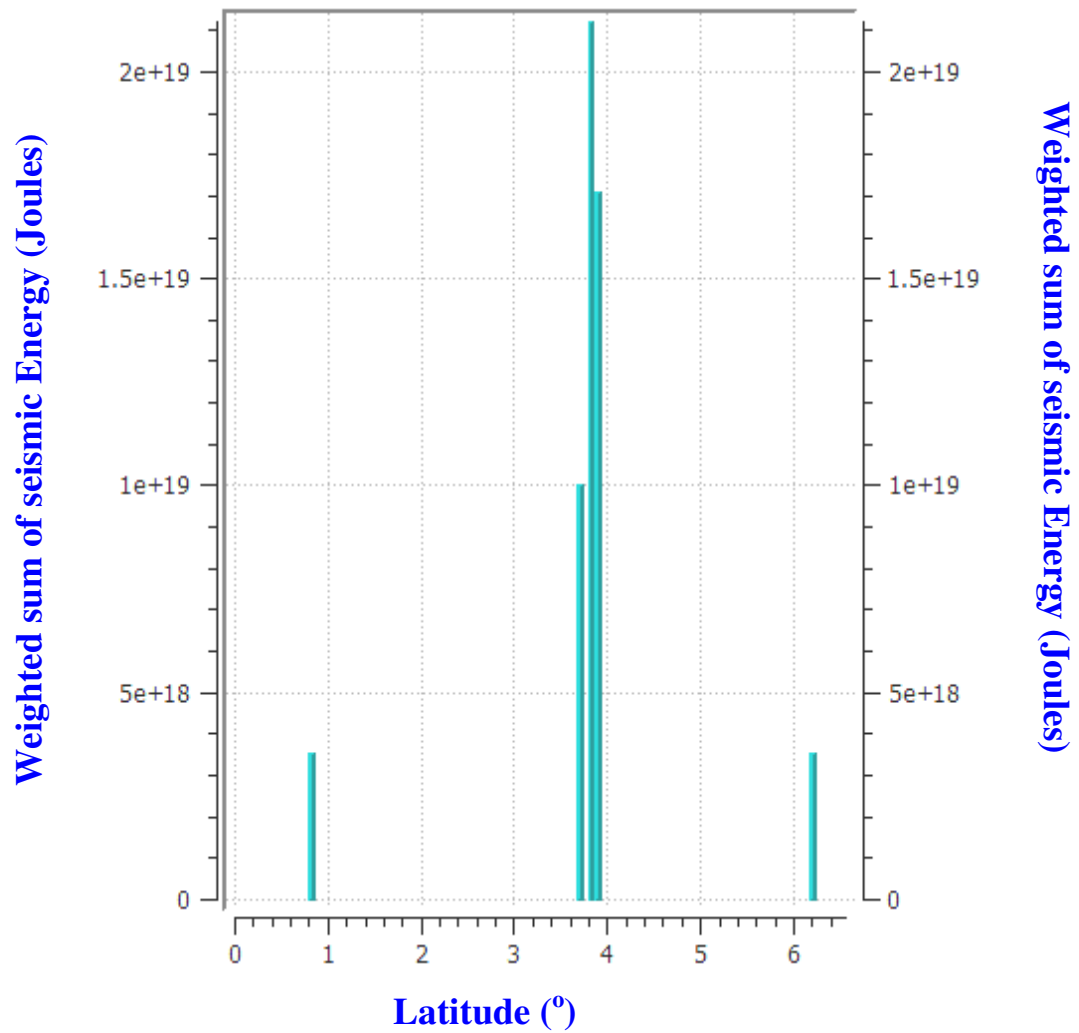


Figure 28: Weighted Sum of Seismic Energy Against Latitude of Earthquakes in Western Africa 1974 – 2013