Journal of Scientific Research & Reports
10(6): 1-8, 2016; Article no.JSRR.20048
ISSN: 2320-0227

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Implication of Focal Depth, Temporal and Magnitude Distribution of Earthquakes in Oceanic Ridges

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Authors' contributions

This work was carried out in collaboration by all authors. Authors OSH, MOA and GOB designed the study and wrote the protocol. Authors OSH, MOA, GOB and AFM analyzed the data. Authors OSH, MOA and AKB interpreted the results. Authors OSH and MOA wrote the first and final draft of the manuscript. Authors GOB, AKB and AFM managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2016/20048
Editor(s):
(1) Shahid Naseem, Department of Geology, University of Karachi, Pakistan.
Reviewers:
(1) Anonymous, Pusan National University, South Korea.
(2) Mohammad Amin Hariri-Ardebili, University of Colorado Boulder, Colorado, USA.
(3) Kwong Fai Andrew Lo, Chinese Culture University, Taiwan.
Complete Peer review History: http://sciencedomain.org/review-history/14272

Original Research Article

Received 8th July 2015
Accepted 12th December 2015
Published 20th April 2016

ABSTRACT

This research aimed at investigating the focal depth, time and magnitude implication of earthquakes associated with the oceanic ridges. Oceanic ridges studied in this research were Mid Atlantic Ridge, Chile Ridge and Pacific ridge. The data were extracted from the earthquake catalogue of Northern California Earthquake Data Centre U.S.A. The data were obtained for the magnitude range of 1.0 - 8.0 for earthquakes that occurred along these oceanic ridges for the period of 1981 - 2010. The data were analyzed using magnitude, focal depth and frequency classification techniques. In the oceanic ridges studied, the shallow focus earthquakes were very predominant. The earthquakes recorded in the Mid-Atlantic Ridge outnumbered the Chile and Pacific Ridge earthquakes. This indicates that the phenomena that are associated with seismicity such as rate of tectonic divergence of oceanic plates, crustal and sub-crustal stress accumulation are enormous in the Mid-Atlantic Ridge. Thus the Atlantic Ocean is mostly prone to the tsunamigenic earthquake risks.

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Keywords: Oceanic ridges; tsunamigenic; focal depth; frequency; magnitude.

1. INTRODUCTION

The discovery of a large number of fracture zones on the mid-oceanic ridges [1-5] has led to a renewed interest in the existence of large horizontal displacement on the oceanic floor and reconsideration of various hypotheses of sea-floor growth, continental drift, and convection currents. The clustering of earthquakes has been long recognized in the mid-oceanic ridge environment [6,7]. Oceanic ridges are centres of ocean floor spreading which is a notable phenomenon that enhances the motion of the lithospheric plates (as showing in Fig. 1). The oceanic ridge system is characterized by an elevated position, extensive faulting, and numerous volcanic structures that have developed on the newly formed crust. An oceanic ridge system can be identified in all the global earthquake sources at the divergent boundary of two plates (as shown in Fig. 1). A Mid-oceanic ridge is a general term for an underwater mountain system that consists of various mountain ranges (chains), typically having a valley known as a rift running along its spine, formed by plate tectonics. The oceanic ridges contribute to the global sources of earthquakes [8,9,10,11]. Majority of earthquakes appearing along the oceanic ridge probably arise from shears' across transform faults connecting section of ridges [12]. The mid oceanic ridges investigated in this work are Mid-Atlantic Ridge**,** Pacific-Antarctic Ridge and Chile Ridge.

This research was embarked upon to study the trend of earthquake distribution along oceanic ridges in order to investigate the stability and tectonic stress accumulation of the lithospheric layers associated with the ridges.

1.1 Mid-Atlantic Ridge

The Mid Atlantic Ridge is mostly underwater mountain range of the Atlantic ocean that runs from 87^0N (about 33 km South of the North pole) to sub-Antarctic Bouvet Island, where it turns into Atlantic-Indian Ridge and continues further east through Crozet plateau to the southwest Indian Ridge, while in the west it is followed by the Scotia Ridge. It is the longest mountain range on earth. The highest peaks of this mountain range extend above the water mark, to form islands.

1.2 Chile Ridge

This is an oceanic ridge with a tectonic divergent plate boundary between the Nazca and Antartctic plates. Its eastern end is the Chile Triple Junction where the Chile ridge is subducted below the South American plate in the Peru-Chile trench. It runs eastward to a tipple point south of the Juan Fernandez Microplate where it intersects the East Pacific Rise.

Fig. 1. A typical mid-oceanic ridge
(Source National Earthquake Information Center (NEIC), US Geological Service)

1.3 Pacific Ridge

The East Pacific Rise is a mid-oceanic ridge, a divergent tectonic plate boundary located along the Pacific Ocean. It separates the Pacific plate to the west from (north to south), the North American Plate, the Rivera Plate, the Cocos Plate, the Nazca Plate, and the Antarctica Plate.

1.4 Formation of Mid-oceanic Ridges and Its Consequences

At oceanic divergent plate boundaries, two oceanic plates move away from one each other. As the plates pull apart from each other in the middle of the oceans, a crack, or rupture, appears. The hot, less dense magma rises through these cracks and cools, pushing the older crust out from the center and creates new ocean floor [9]. This, in turn, causes the growth of oceanic crust on either side of the vents which results in the mid-oceanic ridges. Mid-oceanic ridges are geologically active, with new magma constantly emerging onto the ocean floor and into the crust at and near rifts along the ridge axes. The crystallized magma forms new crust of basalt (known as MORB for Mid-Oceanic Ridge Basalt) and gabbro [13].

There are two processes, ridge-push and slab-pull, thought to be responsible for the spreading seen at mid-oceanic ridges. Ridge-push occurs when the growing bulk of the ridge pushes the rest of the tectonic plates away from the ridge, often towards a subduction zone. At the subduction zone, "slab-pull" comes into effect. This is simply the weight of the tectonic plate being subducted (pulled) below the overlying plate dragging the rest of the plate along. This results into the accumulation of stress and finally earthquake occurrence.

2. DATA ACQUISITION, DESCRIPTION AND METHODS

The data used for this study were extracted from the earthquake catalogue of Advanced National seismic society (ANSS) a Website of Northern California Earthquake Data Centre U.S.A. The data were obtained for the magnitude 1.0- 8.0 for earthquakes that occurred in the zones: latitude -48° to -36°, latitude –50° to 20° and latitude –68° to –58° for the period of 1981-2010. There were 4,360 earthquakes in all. Each datum comprised date of occurrence of earthquake, Origin time, coordinates of epicenter, magnitude, event identification and focal depth of earthquake.

The oceanic ridges studied were located from the seismicity map in Fig. 2 on: latitude -48° to -36° and longitude -110° to -75° (Chile Ridge), latitude -50° to +20° and longitude -45° to -10° (Mid Atlantic Ridge), and latitude -68^0 to -58° and longitude -120° to -18° (Pacific Ridge).

2.1 Classification of Earthquakes According to their Focal Depths

The focus of an earthquake is the actual point underground where rocks break. The depth of the focus can be categorized as shallow (up to 70 km below the surface), intermediate (70 to 300 km), or deep (greater than 300 km). In each region, the earthquakes were analyzed according to their focal depths ranges (Fig. 3).

2.2 Classification of Earthquakes According to their Magnitudes

Magnitude is a measure of the energy released during an earthquake. The Richter scale was used for the earthquake magnitude. Earthquake magnitudes on these scales range from 1–9. The distributions of magnitudes with the number of events in the regions were shown in Figs. 4a – 4c.

2.3 Classification of Earthquakes According to their Frequencies

The frequency of an earthquake refers to the number of times of the ground shaking up and down or back and forth in a certain period of time during an earthquake. Earthquake frequency helps to understand seismic activity of an area [14]. The earthquakes were classified according to their frequencies in order to investigate the variation in the seismicity in the regions of study. The time intervals of 1st decade (1981 – 1990), 2nd decade (1991 – 2000) and 3rd decade (2001 – 2010) were used. The number of events was recorded in each of the regions. The histograms were drawn for each region for proper representation of number of earthquakes in each time interval (Fig. 5).

3. DISCUSSION

In the focal depth distribution of earthquakes in the oceanic ridges shown in Fig. 3, it is clearly seen that the oceanic ridges are embedded with the mostly shallow, few intermediate and a very few deep focus earthquakes. The shallow focus earthquakes were very predominant in all the three ridges studied. The shallow focus earthquakes in the oceanic ridges normally occur at a point very close to the oceanic floor. Therefore, the predominance of shallow focus earthquakes could generate destructive waves within the interior or confine portion of the oceanic ridges. This could result to the triggering of tsunamis even with the low bound earthquake magnitudes. This is in consonance with findings of [15], in which occurrence of a large number of micro to moderate earthquakes at shallow layers recorded during North Sumatra - Andaman region triggered 2004 tsunamigenic earthquake. The point is that the oceanic lithosphere is very thin and weak at the plate boundaries, so the strain cannot build up enough to cause large earthquakes but can cause the volcanic activities along the axis of the ridges (for example, Iceland, Azores, Tristan da Cunha) that can result to large earthquakes along the fault zones in the oceanic floor.

The earthquake magnitudes recorded in all the oceanic ridges investigated (as shown in Figs. (4a – 4c) ranges from 3.0 – 7.9 Richter scale. These magnitudes portray moderate to strong earthquakes but predominantly large number of moderate earthquakes ranging from 4.0 – 4.9 in all the ridges. In view of [16], occurrence of a large number of micro to moderate earthquakes at shallow layers is strong enough to provide faulting mechanisms that can displace huge columns of water beneath the ocean which eventually trigger tsunamigenic earthquakes. Implication of this is that the coaster communities in the neighborhood of the Chile, Atlantic and Pacific oceans are prone to tsunamigenic earthquake risks.

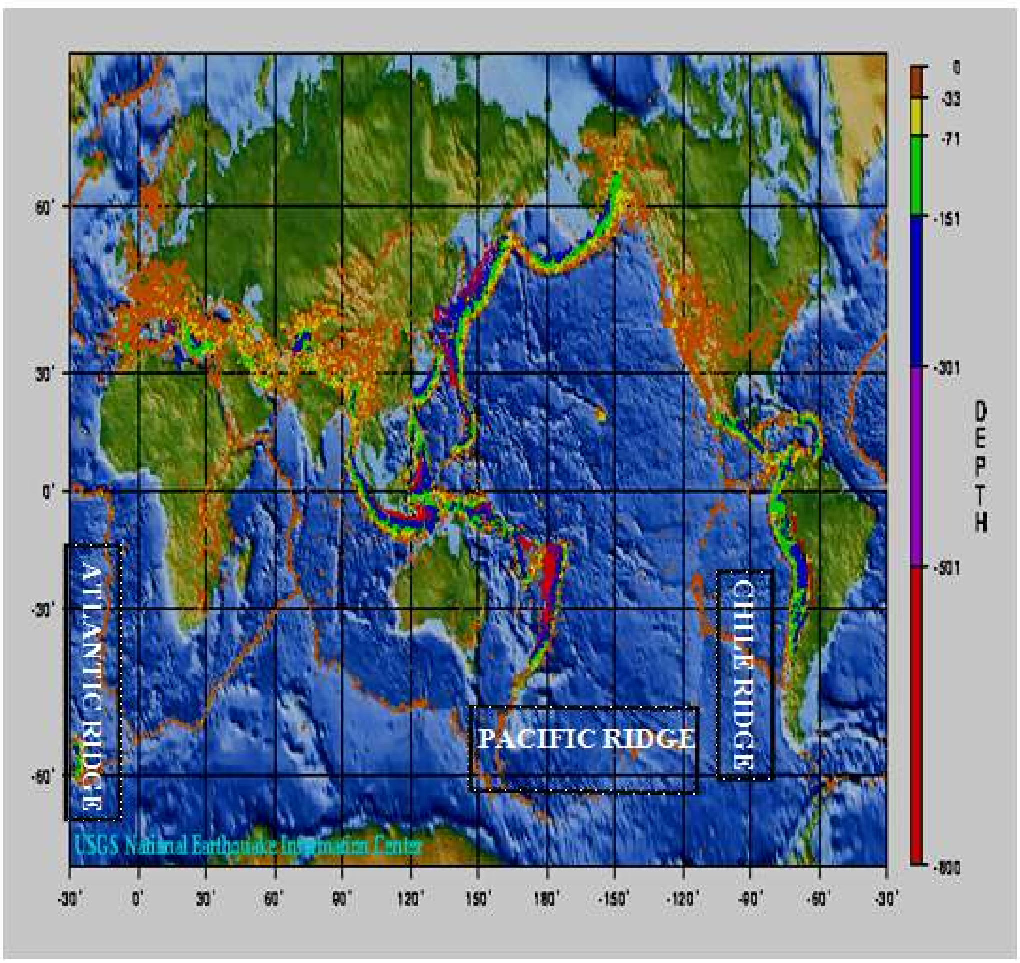

Fig. 2. Map of the global seismicity (1975 – 2010) colour-coded by depth
(Source: National Earthquake Information Center (NEIC), US Geological Service)

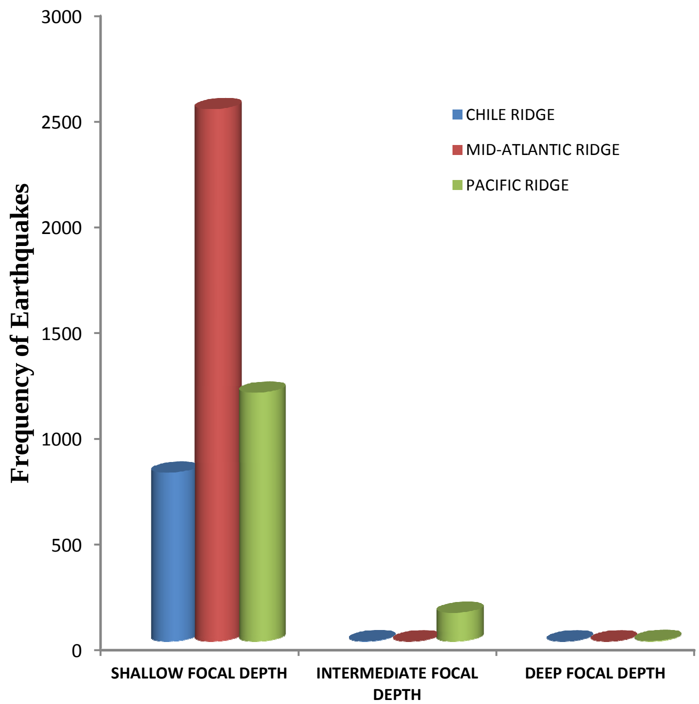

Fig. 3. Focal depth distribution along the oceanic ridges

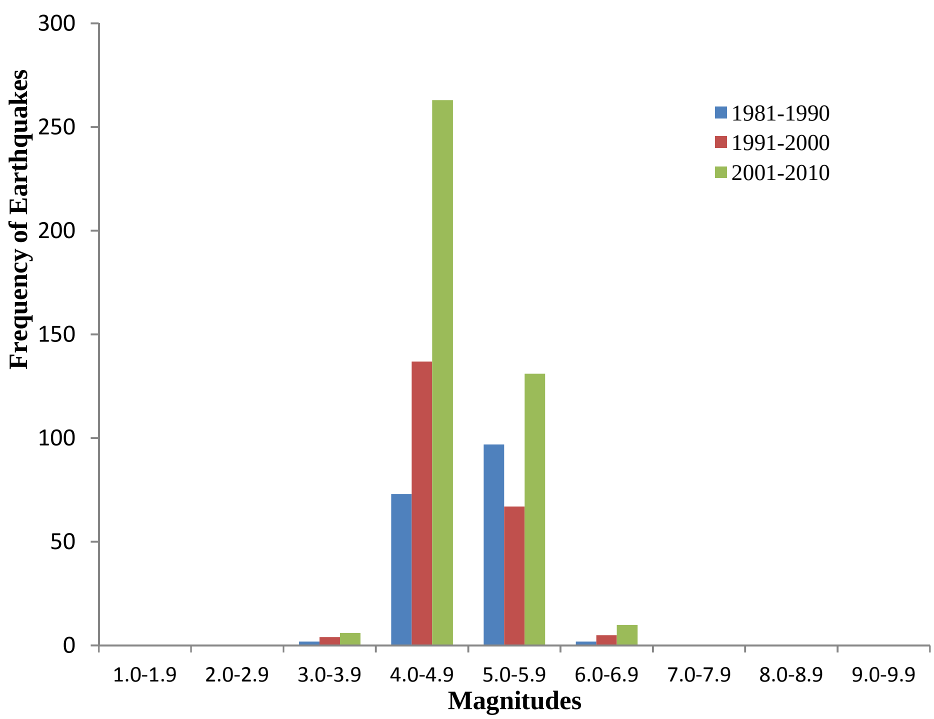

Fig. 4a. Frequency-magnitude distribution of earthquakes in each decade along Chile Ridge

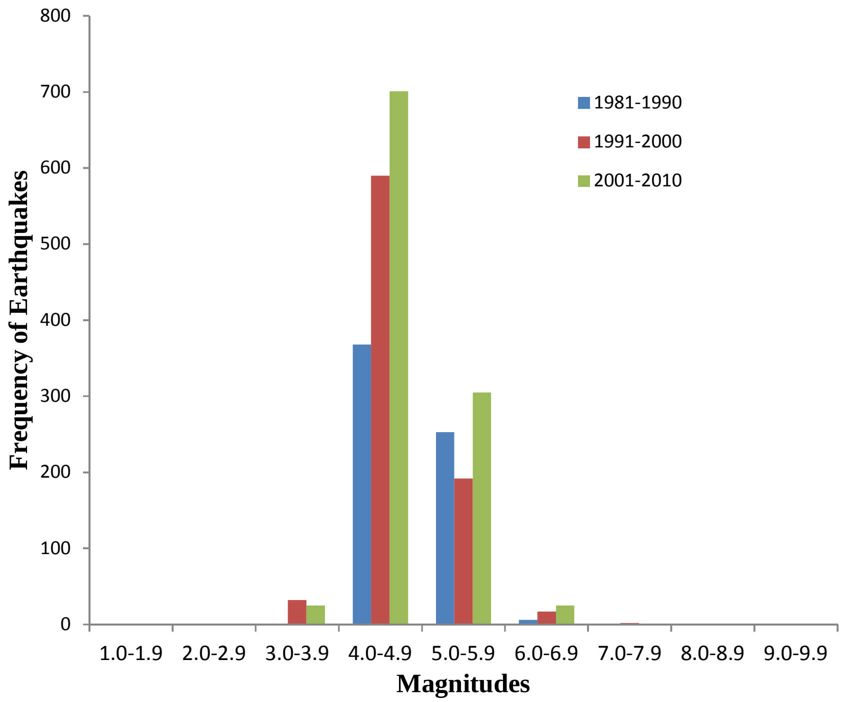

Fig. 4b. Frequency-magnitude distribution of earthquakes in each decade along Mid-Atlantic Ridge

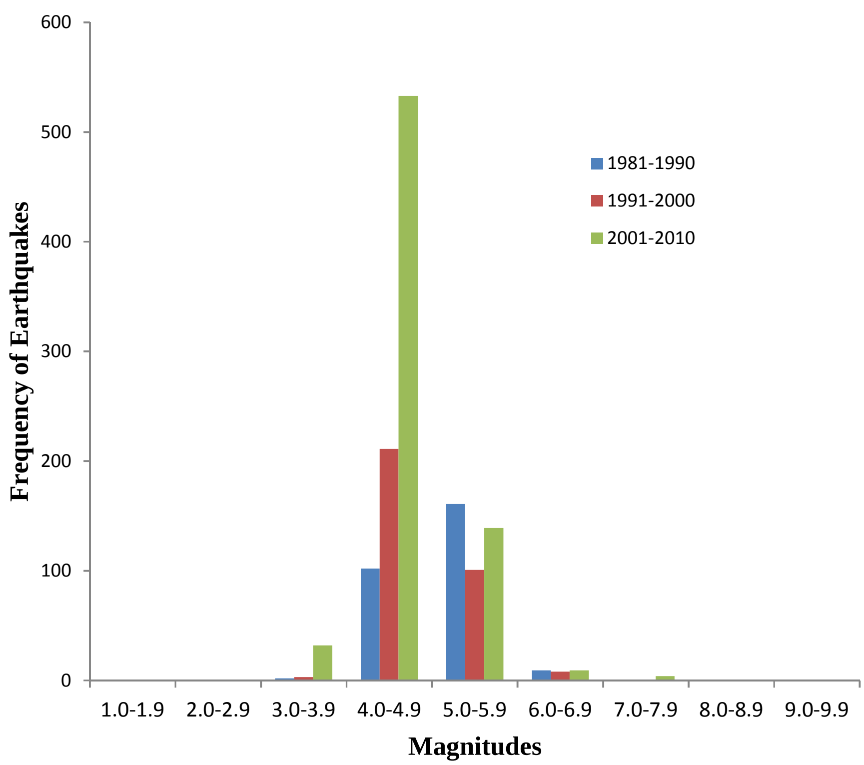

Fig. 4c. Frequency–magnitude distribution of earthquakes in each decade along Pacific Ridge

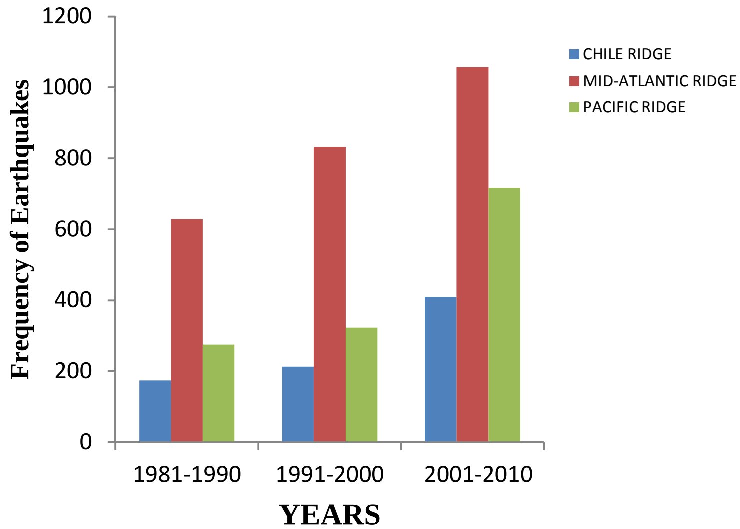

Fig. 5. Frequency distribution of earthquakes in each decade along ridges

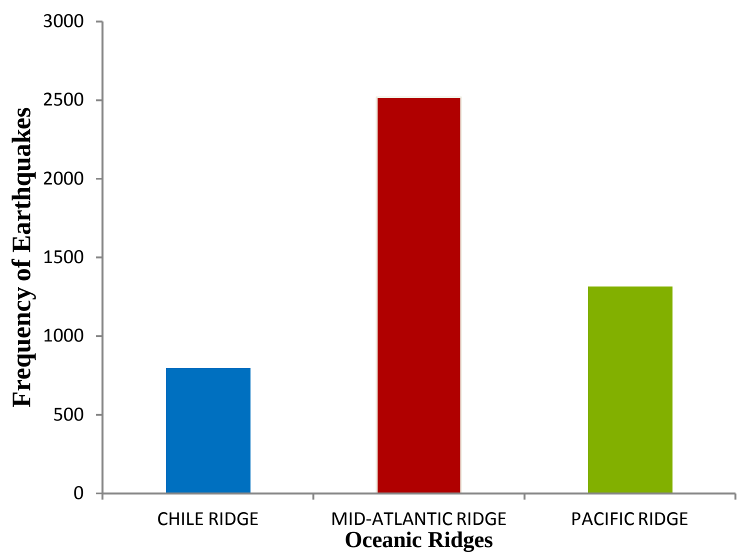

Fig. 6. Frequency distribution of earthquakes in 3 decades in each ridge (1981-2010)

In all the oceanic ridges investigated, it was observed that there was a notable increase in number of earthquakes with time (Fig. 5). This increase in earthquakes with time implies that the relative motion between tectonic divergent oceanic plates during oceanic floor spreading was increasing with time. This increase in relative motion between the plates could enhance a large accumulation of tectonic stress within the divergent oceanic plate boundaries. This fact was corroborated by [16], which pointed out that crustal and sub-crustal stress accumulation as a result of relative motion between the divergent oceanic plates depend upon the increase in number of earthquakes concentrating at a particular layer near the oceanic ridges. In view of this, continuous accumulation of stress may eventually evolve tsunamigenic earthquakes.

The earthquakes recorded in the Mid-Atlantic Ridge outnumbered the Chile and Pacific Ridge earthquakes (Fig. 6). This indicates that the phenomena that are associated with seismicity such as rate of tectonic divergence of oceanic plates, crustal and sub-crustal stress accumulation are enormous in the Mid-Atlantic Ridge. Therefore the Atlantic Ocean is mostly prone to the tsunamigenic earthquake risks.

4. CONCLUSION

The oceanic ridges are embedded with mostly shallow, few intermediate and very scanty deep focus earthquakes. These earthquakes occurred as a result of continuous accumulation of stress at the tectonic divergent oceanic plates.

The shallow focus earthquakes were very predominant in all the ridges studied. The predominance of the shallow focus earthquakes could generate destructive waves within the interior or confine portion of the oceanic ridges which could result to the triggering of tsunamis even with the low bound earthquake magnitudes.

Coaster communities in the neighborhood of the Chile, Atlantic and Pacific oceans are prone to tsunamigenic earthquake risks but the Atlantic Ocean is mostly prone to these risks.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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