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ESTIMATION OF RETURN PERIODS AND EARTHQUAKE OCCURRENCE RISK IN SOME OCEANIC RIDGES USING POISSON'S MODEL

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ABSTRACT

This study estimated return periods and earthquake occurrence risk in some Oceanic Ridges using Poisson's model. A 115-year earthquake data from 1st January 1901 to 31st December 2015 were extracted from the earthquake catalogue, International Seismological Centre, Pipers Lane, Thatcham, Berkshire, United Kingdom. The selected data consisted of earthquakes with magnitude $M_b \geq 4.0$ with focal depth of 0-700km. A total of 8,932 events were employed in the study with Chile Ridge having 1440, Mid-Atlantic Ridge 4564 and Pacific Ridge 2928. The findings of this study revealed that in Chile Ridge the occurrence possibility of an earthquake with magnitude $Mb \geq 8.0$ within 10 years is 0.2505 and 100 years is 0.9441 with return period of 34.67 years. Similarly, in Mid-Atlantic Ridge the occurrence possibility of an earthquake with magnitude $Mb \geq 8.0$ within 10 years is 0.6828 and 100 years is 1.0000 with return period of 8.71 years. For Pacific Ridge, the occurrence possibility of an earthquake with magnitude $Mb \geq 8.0$ within 10 years is 0.6152 and 100 years is 0.9999 with return period of 10.47 years. It was also observed that as the earthquake magnitudes are increasing, the corresponding earthquakes risks are decreasing. It is found that Chile Ridge has a higher return period for earthquake of magnitude 8.0 compared to Mid-Atlantic Ridge and Pacific Ridge. But earthquake occurrence cannot be predicted with certainty because the concept of earthquake prediction is still a complicated issue due to saturation of earthquake magnitudes and variation of data collection by different seismic stations and networks

KEYWORD: Return periods, oceanic ridges, Poisson's model, probability, earthquakes.

INTRODUCTION

A mid-ocean ridge is an underwater mountain system developed by plate tectonics when two oceanic plates diverge. It consists of many mountains joined in chains with a valley called a rift running along its spine. Mid-ocean ridges are geologically active, with new magma constantly evolving onto the ocean floor and into the crust at and near rifts along the ridge axes. Mid-ocean Ridge divides the boundary between two tectonic plates called a divergent plate boundary. Spreading rate on earth varies between less than 10 mm/yr at the Gakkel Ridge in the Arctic Ocean (Dick, 2003) and 170 mm/yr at the East Pacific Rise (Macdonald, 2001). The spreading rate comprises slow-spreading ridges (full spreading rates 55mm/yr), intermediate-spreading ridges (55–80 mm/yr) and fast-spreading ridges (>80 mm/yr) (Dick, 2003 and Buck et al., 2005).

Slow-spreading ridges are made up of axial rift valleys and a general rough topography, while fast-spreading ridges consist of axial highs and a much smoother topography. Intermediate-spreading ridges may compose of axial highs, axial valleys and transitional morphologies exhibited by a faulted topography with neither axial high nor valley (Phillips and Chen, 1993). Also Kappel and Ryan, (1986) pointed that ridges with intermediate spreading rates can also vary through time.

The Oceanic ridges considered in this work are Chile Ridge, Mid-Atlantic Ridge and Pacific Ridge. Chile Ridge is one of the few regions where we have a triple junction (a place where three plate boundaries meet), the Pacific Ridge which is located within the Ring of fire (a major area in the basin of the Pacific Ocean where a large number of earthquakes and volcanic eruptions occur) and the Mid-Atlantic Ridge which is a divergent tectonic plate boundary situated along the floor of the Atlantic Ocean and in the South Atlantic. It demarcates the African and South American plates and plate boundaries within this Ridge (e.g. The African plate which moves at a speed of about 2.15cm per year towards the Eurasian plate). Also coastal communities within the Chile Ridge and Pacific Ridge are prone to high earthquake risks.

It is on the basis of these that this study is conducted to estimate return periods and earthquake occurrence risk in some Oceanic Ridges using Poisson's model.

Seismicity of the study area

Chile Ridge

The Chile Ridge also referred to as Chile Rise is an Oceanic Ridge, a tectonic divergent plate boundary that is situated between the Nazca and Antarctic Plates. Its eastern end is the Chile Triple Junction where the Chile Rise is being subducted below the South American Plate in the Peru - Chile Trench (Russo et al., 2010). It extends westward to a triple point south of the Juan Fernández microplate where it intersects the East Pacific Rise (Larson et al., 1992) to the triple junction of the Antartic, Nazca and South American plates close to 46^0S along southern Chile trench (Herron et al., 1981; Cande et al., 1987). The coast of Chile has witnessed earthquakes of high magnitude greater than 7.0 since 1973. The greatest instrumentally recorded quake in the world happened off the coast of Chile in 1960 with magnitude 9.5. Earth scientists are concerned about Chile Ridge not because of the history of great earthquakes but because of its tectonic setting. Chile is one of the few regions where three major plates join i.e it is a triple junction.

Mid –Atlantic ridge

The Mid-Atlantic Ridge is the major geologic unit of Mid-Atlantic Ocean. It extends from Iceland to Antarctic and is the longest underwater mountain range on Earth. The ridge was developed by an oceanic rift which demarcates the North American Plate and the Eurasian Plate in the North Atlantic Ocean. In the South Atlantic, the Mid-Atlantic Ridge demarcates the South American Plate and the African Plate. The Mid-Atlantic Ridge is a divergent boundary initially developed during the Triassic period when a series of two arms of three-armed grabens joined to the supercontinent Pangea to form the ridge.

Pacific Ridge

The East Pacific Rise (or Ridge) is a Mid-Oceanic Ridge, a divergent tectonic plate boundary situated along the floor of 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 Antarctic Plate.

MATERIALS AND METHODS

Source of data

The data set for this work were extracted from International Seismological Centre (ISC), Pipers Lane, Thatcham, Berkshire, United Kingdom. The selected data consisted of earthquakes with $M_b \geq 4.0$ for the study area from 1st January 1901 to 31st December 2015 (115years) with focal depth from 0 – 700km. The data set comprised date of occurrence of earthquake, origin time, coordinates of epicentre, magnitude, event identification, focal depth of earthquake and event type E. The region of study is situated within the coordinates; Chile Ridge latitudes: 48^0S – 36^0S and longitudes: 110^0W–75^0W; Mid-Atlantic Ridge latitudes: 50^0S – 20^0N and 45^0W – 10^0W; Pacific Ridge latitudes: 68^0S – 58^0S and longitudes: 120^0W–150^0W (Fig.1). A total of 8,932 events were employed in the study with Chile Ridge having 1440, Mid-Atlantic Ridge 4564 and Pacific Ridge 2928 respectively.

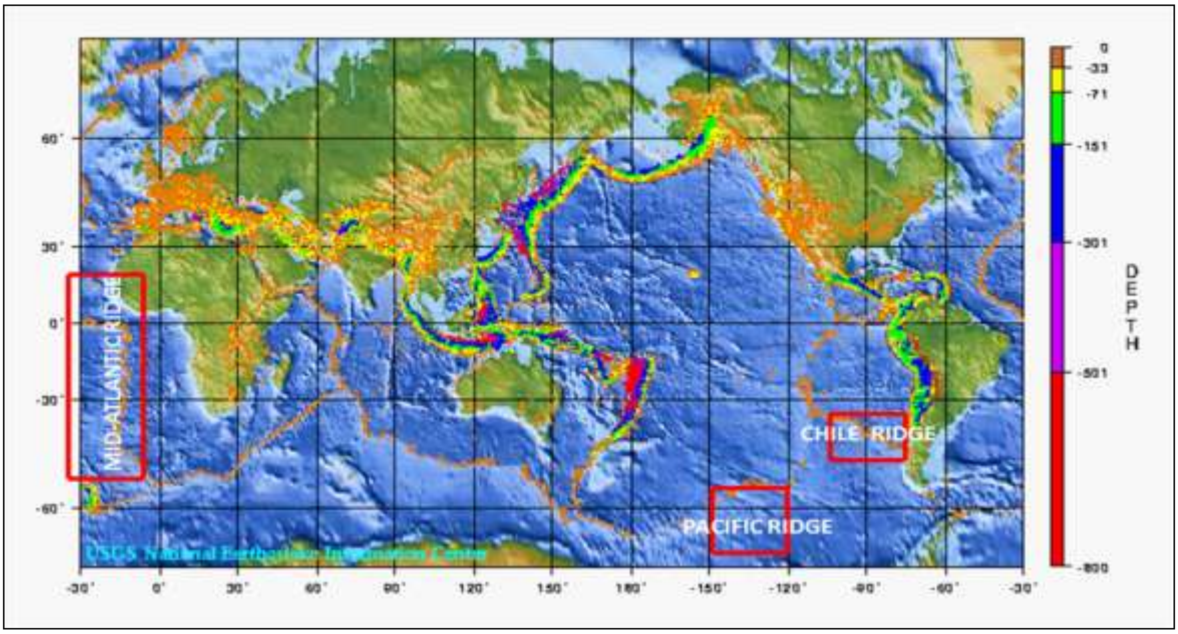

Fig. 1: Map of Global seismicity (1975 – 2010) colour- coded depth. (Source: National Earthquake Information Centre, US Geological Service) Modified from (Hammed et al., 2016).

Poisson’s model

The earthquake risk parameters are defined using Poisson’s method (Unal et al., 2014).

$$n(M) = 10^{a-bM} \tag{1}$$

$$R(M) = 1 - e^{-n(M)T} \tag{2}$$

$$Q = \frac{1}{n(M)} \tag{3}$$

Where n(M) is the annual average number of earthquakes, R(M) is the risk of occurrence of an earthquake with magnitude M within T years, in a given region for a t-year observation interval and Q is the return (recurrence) period.

Gutenberg – Richter's relationship

Gutenberg and Richter in 1954 developed a relationship for the frequency–magnitude distribution (FMD), in the form:

$$\text{LogN} = a - bM \qquad (4)$$

For a given region and time interval, eqn (4) gives the cumulative number of earthquakes (N) with magnitude (M), where a and b are positive, real constants. The parameter *a* describes the seismic activity. It is determined by the event rate and for a given region depends on the volume and time window used. The *b* parameter is a tectonic parameter that describes the properties of the seismic medium.

RESULTS AND DISCUSSION

The results of the study are as shown (Table 1 - Table 4 and Fig.2 – Fig.8).

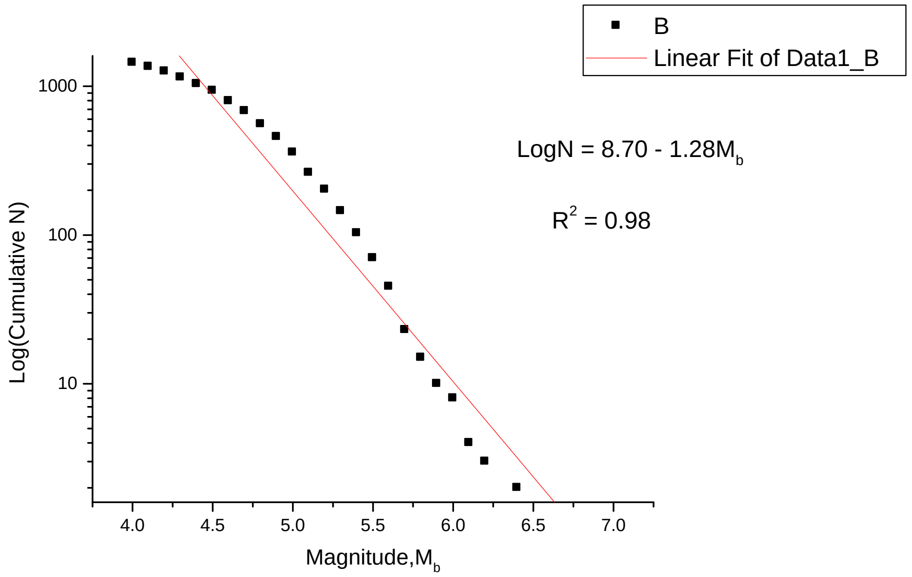

Fig. 2: Cumulative frequency-magnitude relationship in Chile Ridge.

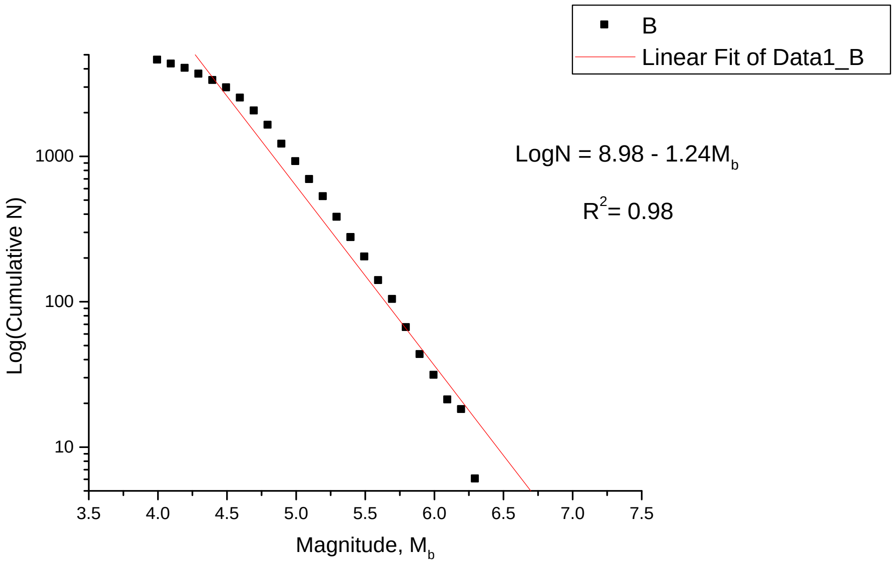

Fig. 3: Cumulative frequency-magnitude relationship in Mid-Atlantic Ridge.

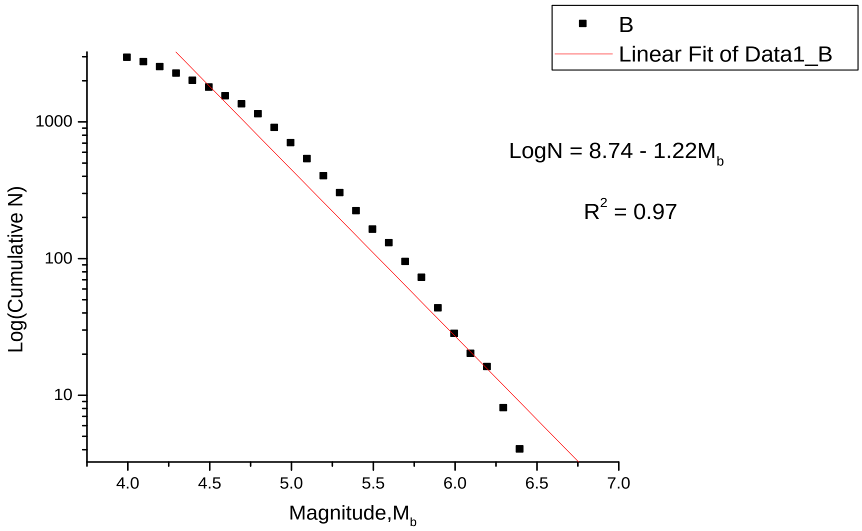

Fig. 4: Cumulative frequency-magnitude relationship in Pacific Ridge.

Table 1: Magnitude, probability and return period obtained by using Gutenberg-Richter's model for Chile Ridge.

M_b	N(M)	1year	5years	10years	20years	30years	40years	50years	75years	100years	Q
4.0	3801.894	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0003
4.5	870.9636	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0011
5.0	199.5262	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0050
5.5	45.7088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0219
6.0	10.4713	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0955
6.5	2.3988	0.9092	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.4167
7.0	0.5495	0.8379	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.8198
7.5	0.1259	0.1183	0.4671	0.7160	0.9194	0.9771	0.9935	0.9982	0.9992	1.0000	7.9434
8.0	0.0288	0.0284	0.1343	0.2505	0.4383	0.5790	0.6845	0.7635	0.8850	0.9441	34.6741

Table 2: Magnitude, probability and return period obtained by using Gutenberg-Richter's model for Mid-Atlantic Ridge.

M_b	N(M)	1year	5years	10years	20years	30years	40years	50years	75years	100years	Q
4.0	10471.2854	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0001
4.5	2511.8864	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0004
5.0	602.5595	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0017
5.5	144.5440	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0069
6.0	34.6737	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0288
6.5	8.3176	0.9997	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.1202
7.0	1.9952	0.8640	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.5010
7.5	0.4786	0.3804	0.9087	0.9917	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	2.0893
8.0	0.1148	0.1085	0.4368	0.6828	0.8994	0.9681	0.9899	0.9968	0.9998	1.0000	8.7097

Table 3: Magnitude, probability and return period obtained by using Gutenberg-Richter's model for Pacific Ridge.

M_b	N(M)	1year	5years	10years	20years	30years	40years	50years	75years	100years	Q
4.0	7244.3596	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0001
4.5	1778.2790	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0006
5.0	436.5158	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0023
5.5	107.1519	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0093
6.0	26.3027	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0380
6.5	7.2440	0.9993	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.1380
7.0	1.5848	0.7950	0.9996	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.6310
7.5	0.3890	0.3223	0.8570	0.9796	0.9996	1.0000	1.0000	1.0000	1.0000	1.0000	2.5704
8.0	0.0955	0.0911	0.3796	0.6152	0.8519	0.9430	0.9781	0.9916	0.9992	0.9999	10.4713

Table 4: Return periods in Chile, Mid-Atlantic and Pacific Ridges.

Magnitude, M_b	Chile Ridge	Mid-Atlantic Ridge	Pacific Ridge
4.0	0.0003	0.0001	0.0001
4.5	0.0011	0.0004	0.0006
5.0	0.0050	0.0017	0.0023
5.5	0.0219	0.0069	0.0093
6.0	0.0955	0.0288	0.0380
6.5	0.4169	0.1202	0.1380
7.0	1.8198	0.501	0.6310
7.5	7.9434	2.0893	2.5704
8.0	34.6741	8.7097	10.4713

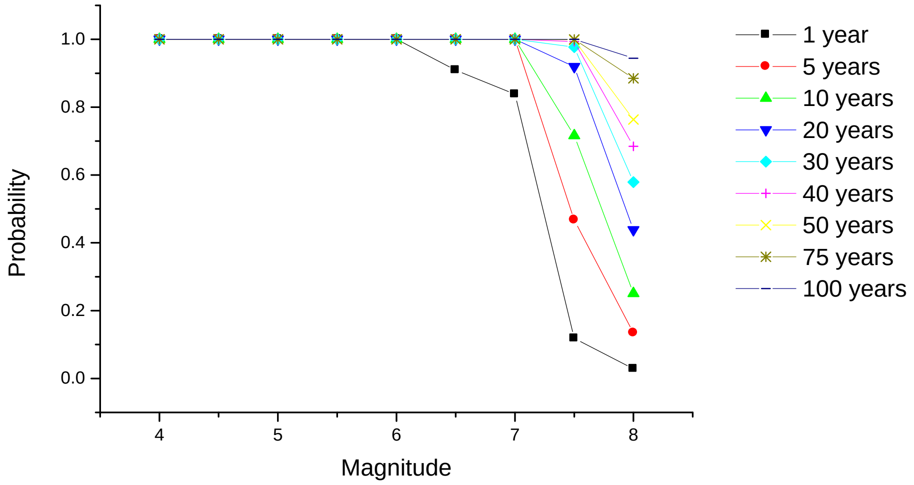

Fig. 5: Probabilities of exceeding earthquakes in Chile Ridge.

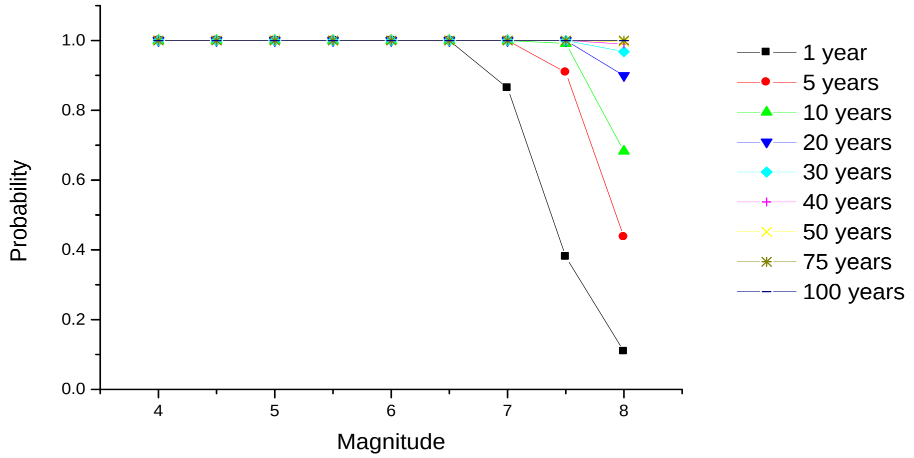

Fig.6: Probabilities of exceeding earthquakes in Mid-Atlantic Ridge.

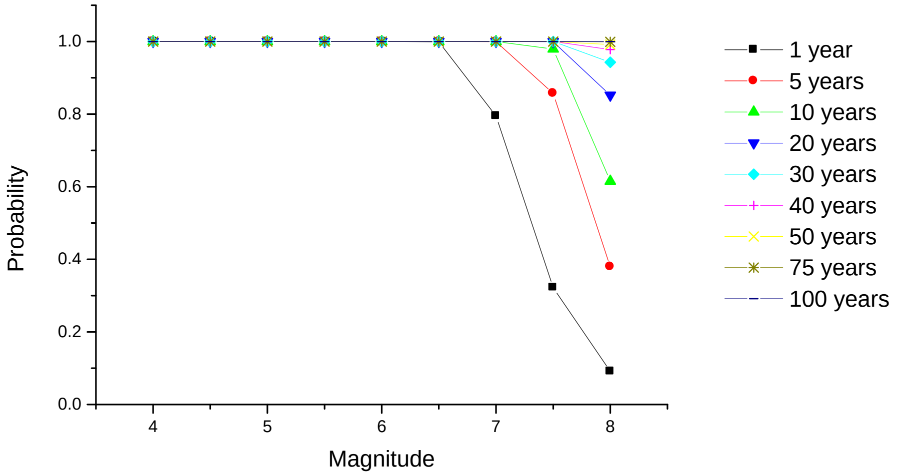

Fig. 7: Probabilities of exceeding earthquakes in Pacific Ridge.

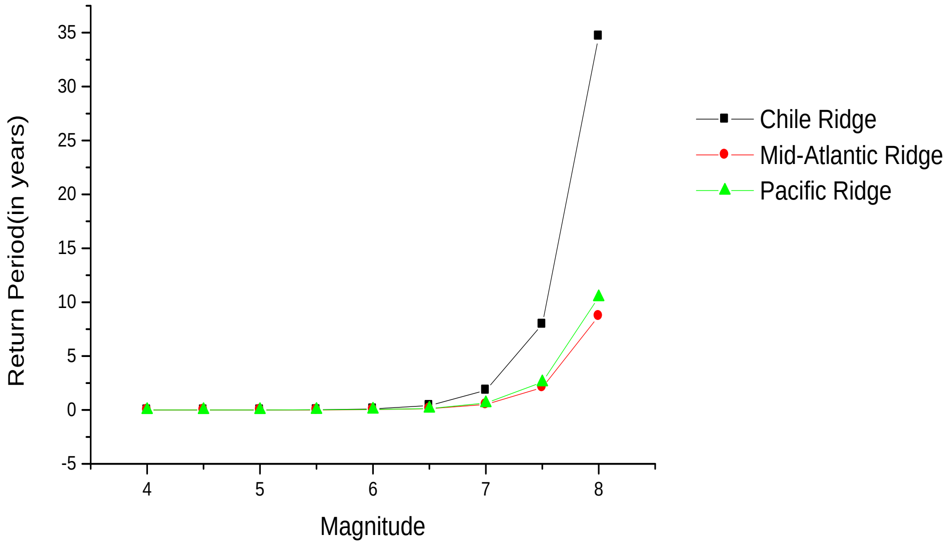

Fig. 8: A graph of return period and magnitude in Chile, Mid-Atlantic and Pacific Ridges.

To calculate the probabilities of earthquake occurrence and return periods, the frequency-magnitude relationship was examined using Gutenberg-Richter (GR) model. The results obtained with the GR models yielded LogN = 8.70 – 1.28M_b in Chile Ridge; LogN = 8.98 – 1.24M_b in Mid-Atlantic Ridge and LogN = 8.74 – 1.22M_b in Pacific Ridge for the frequency-magnitude relationship with coefficient of determination R^2 = 0.98, R^2 = 0.98 and R^2 = 0.97 (Fig.2 to Fig.4). This implies that earthquake data can be well described with these models.

Earthquake risk parameter estimations, seismic risk and return periods for GR models are as in Table 1 to Table 3. The possibilities of exceeding the earthquake magnitudes in the (T=115years) periods for these models are as in Fig.5 to Fig.7. 1-year, 5-years, 10-years, 20-years, 30-years, 40-years, 50-years, 75-years and 100-years were employed in these calculations (eqn(1) to eqn(3)). A time window of T = 115 years data was employed to estimate the risk values and return periods from 1-year to 100-year periods. Based on this study, it was revealed that in Chile Ridge the occurrence possibility of an earthquake with magnitude Mb≥8.0 within 10 years is 0.2505, 20 years is 0.4383, 30 years is 0.5790, 40 years is 0.6845, 50 years is 0.7635, 75 years is 0.8850, and 100 years is 0.9441 with return period of 34.67 years. Similarly, in Mid-Atlantic Ridge the occurrence possibility of an earthquake with magnitude Mb≥8.0 within 10 years is 0.6828, 20years is 0.8994, 30years is 0.9681, 40 years is 0.9899, 50 years is 0.9968, 75 years is 0.9998, and 100 years is 1.0000 with return period of 8.71 years. For Pacific Ridge, the occurrence possibility of an earthquake with magnitude Mb≥8.0 within 10 years is 0.6152, 20 years is 0.8519, 30 years is 0.9430, 40 years is 0.9781, 50 years is 0.9916, 75 years is 0.9992 and 100 years is 0.9999 with return period of 10.47 years. Probabilities of exceeding earthquake magnitudes in given periods for GR models are as shown (Table 1 to Table3 and Fig.5 to Fig.7) respectively. It is observed that as the earthquake magnitudes are increasing, the corresponding earthquake risks are decreasing. Also the probability of earthquake occurrence increases as the year increases.

Also Table 4 and Fig.8 indicate that between earthquake magnitude 4.0 and 6.0, the return periods are almost the same with values less than 0.1 year. This implies that earthquake within these magnitude range may occur frequently as compared to earthquakes of magnitude 6.5 – 8.0 and above. As the earthquake magnitudes are increasing the return periods are also increasing. Also Chile Ridge has a higher return period for earthquake of magnitude 8.0 compared to Mid-Atlantic Ridge and Pacific Ridge.

CONCLUSION

This study showed that earthquake of magnitude 8.0 in Chile Ridge has return period of 34.67 years; in Mid-Atlantic Ridge it has a return period of 8.71 years and in Pacific Ridge it has a return period of 10.47 years. It is observed that as the earthquake magnitudes are increasing, the corresponding earthquake risks are decreasing. It is also revealed that for earthquake of magnitude 4.0 and 6.0, the return periods are almost the same with values less than 0.1 year. This implies that earthquake within these magnitude range may occur frequently as compared to earthquakes of magnitude 6.5 – 8.0 and above. But earthquake occurrence cannot be predicted with certainty because the concept of earthquake forecast/prediction is still a complicated issue due to saturation of earthquake magnitudes and variation of data collection by different seismic stations and networks. The implication of this study is that it gives us information about return periods of earthquakes that may occur in the studied oceanic ridges and this will help in planning and predictions.

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