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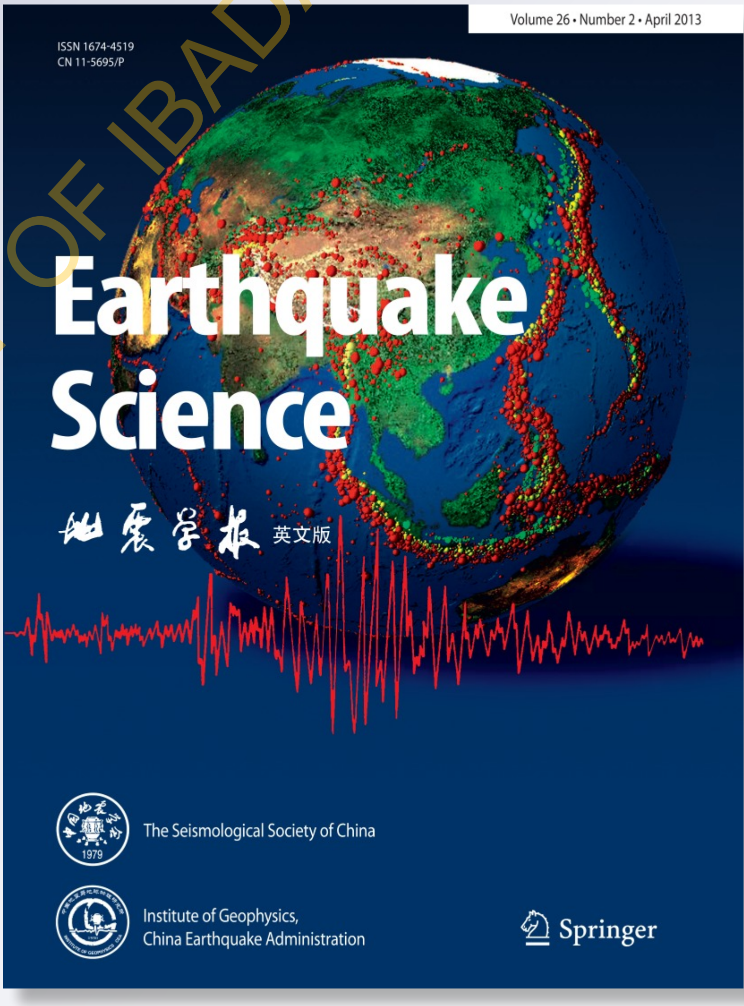

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RESEARCH PAPER

Focal depth, magnitude, and frequency distribution of earthquakes along oceanic trenches

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Abstract The occurrence of earthquakes in oceanic trenches can pose a tsunami threat to lives and properties in active seismic zones. Therefore, the knowledge of focal depth, magnitude, and time distribution of earthquakes along the trenches is needed to investigate the future occurrence of earthquakes in the zones. The oceanic trenches studied, were located from the seismicity map on: latitude +51° to +53° and longitude −160° to 176° (Aleutian Trench), latitude +40° to +53° and longitude +148° to +165° (Japan Trench), and latitude −75° to −64° and longitude –15° to +30° (Peru–Chile Trench). The following features of seismic events were considered: magnitude distribution, focal depth distribution, and time distribution of earthquake. The results obtained in each trench revealed that the earthquakes increased with time in all the regions. This implies that the lithospheric layer is becoming more unstable. Thus, tectonic stress accumulation is increasing with time. The rate of increase in earthquakes at the Peru–Chile Trench is higher than that of the Japan Trench and the Aleutian Trench. This implies that the convergence of lithospheric plates is higher in the Peru–Chile Trench. Deep earthquakes were observed across all the trenches. The shallow earthquakes were more prominent than intermediate and deep earthquakes in all the trenches. The seismic events in the trenches are mostly of magnitude range 3.0–4.9. This magnitude range may indicate the genesis of mild to moderate tsunamis in the trench zone in near future once sufficient slip would occur with displacement of water column.

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Keywords Focal depth · Magnitude · Earthquake · Oceanic trenche

1 Introduction

The oceanic trenches are hemispheric-scale, long but narrow topographic depressions of the sea floor and are also the deepest parts of the ocean floor. Trenches define one of the most important natural boundaries on the Earth's solid surface. Trenches are distinctive morphological features of plate boundaries. Along convergent plate boundaries, plates move together at rates that vary from a few millimeters to over 10 cm per year (Ladd et al. 1990). A trench marks the position at which the flexed, subducting slab begins to descend beneath another lithospheric slab. Trenches are generally parallel to a volcanic island arc, and about 200 km from a volcanic arc (Wright et al. 2000). Oceanic trenches typically extend 3–4 km below the level of the surrounding oceanic floor. Oceanic lithosphere moves into trenches at a global rate of about a tenth of a square metre per second (Smith and Sandwell 1997).

Trenches generally have the form of arcs (Hawkins et al. 1984). They are found concentrating around the boundary of the Pacific basin and in other scattered locations around the globe (Stern 2002).

The aim of this research is to study the trend of earthquake parameters along oceanic trenches in order to

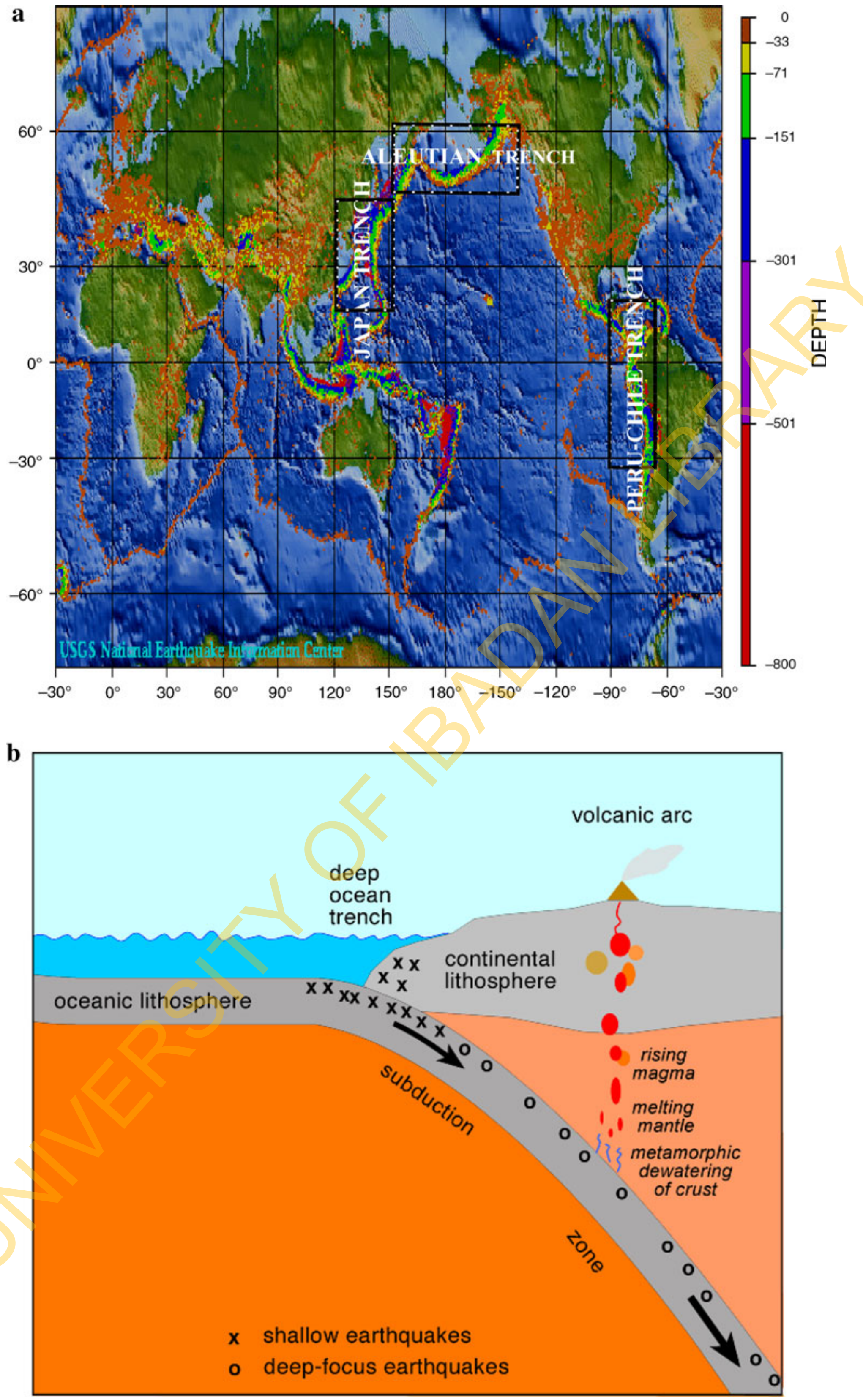

Fig. 1 **a** Map of the global seismicity 1975–2010, *color coded* by depth. [*Source* National Earthquake Information Center (NEIC), US Geological Service]. **b** Schematic diagram showing the triggering of earthquakes due to the trench formation at convergent plate boundaries. (http://myweb.cwpost.liu.edu/vdivener/notes/subd_zone.htm)

investigate the stability and tectonic stress accumulation of the lithospheric layers associated with the trenches.

1.1 Trench formation and its consequences

Trenches are formed at convergent plate boundaries where two plates slide toward each other commonly forming a subduction zone (if one plate moves underneath the other) or a continental collision (if the two plates contain continental crust) (as shown in Fig. 1b). The collision of plates leads to the formation of deep fractures in the lithosphere which may be locked up for months or hundreds of years. This basic knowledge of trench formation corroborates with the concept of stress accumulation and genesis of earthquakes in the subducting plate regime due to structural heterogeneities as witnessed from the seismic imaging of the subduction zone in and around the Japan Trench (Mishra et al. 2003; Mishra and Zhao 2004).

Some of the deep oceanic trenches (as shown in Fig. 1) are Peru–Chile Trench, Japan Trench, and Aleutian Trench.

1.2 Peru–Chile Trench

The Peru–Chile Trench is a submarine trench in the eastern Pacific Ocean about 160 km off the coast of Peru and Chile. It reaches a maximum depth of 8,065 m below sea level and is approximately 95,900-km long; its mean width is 64 km and it covers an expanse of some 59,000 km^2) (Stern 2002). The trench is a result of the eastern edge of the Nazca plate being subducted under the South American plate. The Peru–Chile Trench, the fore arc and the western edge of the central Andean Plateau (Altiplano) delineate the dramatic Bolivian Orocline that defines the Andean slope of southern Peru, northern Chile, and Bolivia.

1.3 Japan Trench

The Japan Trench is an oceanic trench, a part of the Pacific Ring of Fire, in the floor of the northern Pacific Ocean off North-East Japan. It extends from the Kuril Islands to the Bonin Islands and is 9,000 m at its deepest. It is an extension of the Kuril–Kamchatka Trench to the north and the Izu-Ogasawara Trench to its south with a length of 800 km. This trench is created when the oceanic Pacific plate subducts beneath the continental Okhotsk plate (Jarrard 1986). The subduction process causes bending of the down going plate, creating a deep-sea trench. Continuing movement on the subduction zone associated with the Japan Trench is one of the main causes of tsunamis and earthquakes in northern Japan.

1.4 Aleutian Trench

The Aleutian Trench (or Aleutian Trough) is a subduction zone and oceanic trench which runs along the southern coastline of Alaska and the adjacent waters of North-Eastern Siberia off the coast of Kamchatka Peninsula. It is classified as a "marginal trench" in the east as it runs along the margin of the continent, and as an island arc where it runs through the open sea. The trench extends for 3,400 km from a triple junction in the west with the Ulakhan Fault and the northern end of the Kuril–Kamchatka Trench, to a junction with the northern end of the Queen Charlotte Fault system in the east. The Aleutian Trench forms part of the boundary between two tectonic plates. Here, the Pacific plate is being subducted under the North American Plate at an angle of nearly 45° (Hamilton 1988). The deepest part of the Aleutian is 7,679 m. North of the trench, a string of volcanoes and associated islands have formed where melting of the crust has been caused by the descending plate beneath them.

2 Data acquisition, description, and method

The data used for this study were extracted from the earthquake catalog of Advanced National seismic system a Website of Northern California Earthquake Data Centre USA. (http://quake.geo.berkeley.edu/cnss/). The data were obtained for the magnitude 1.0–8.0 for earthquakes that occurred in the zones: latitude +51° to +53°, latitude +40° to +53°, and latitude −75° to −64° for the period of 1981–2010. There were 33,783 earthquakes in all. Each datum composed the date of occurrence of earthquake, origin time, coordinates of epicenter, magnitude, event identification, and focal depth of earthquake.

The oceanic trenches studied, were located from the global seismicity map (Fig. 1) on: latitude +51° to +53° and longitude −160° to 176° (Aleutian Trench), latitude +40° to +53° and longitude +148° to +165° (Japan Trench), and latitude −75° to −64° and longitude −15° to +30° (Peru–Chile Trench).

The following features of the events were considered: focal depth distribution, magnitude distribution, and time distribution.

2.1 Focal depths distribution

In each region, the earthquakes were categorized according to their focal depths using the following ranges:

1. Shallow earthquakes; occurring at 0–70 km.
2. Intermediate earthquakes; occurring at 71–300 km.

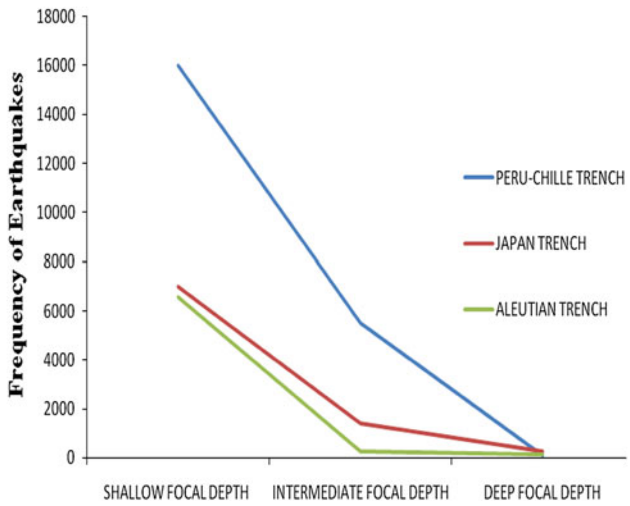

Fig. 2 Focal depth distribution of earthquakes along trenches

3. Deep earthquakes; occurring at 301–700 km.

2.2 Magnitude distribution of earthquakes

The magnitude is the most often cited measure of an earthquake's size, but it is not the only measure. In fact, there are different types of earthquake size measures. Early estimates of earthquake size were based on non-instrumental measures of the earthquakes effects. For example, we could use values such as the number of fatalities or injuries, the maximum value of shaking intensity, or the area of intense shaking. The problem with these measures is that they do not correlate well. The damage and devastation produced by an earthquake will depend on its location, depth, proximity to populated regions, as well as its "true" size. Even for earthquakes close enough to population centers values such as maximum intensity and the area experiencing a particular level of shaking did not correlate well. With the invention and deployment of seismometers it became possible to accurately locate earthquakes and measure the ground motion produced by seismic waves. It was natural for these instrumental measures to be used to compare earthquakes, and one of the first ways of quantifying earthquakes using seismograms was the magnitude. In this work, Richter's magnitude scale was employed in quantifying the size of the earthquakes along the trenches. The distributions of magnitudes with the number of events in all the trenches are shown in Figs. 3, 4, 5, 6, 7, 8, 9, 10, and 11 respectively.

2.3 Frequency distribution of earthquakes

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 (Ghosh 2007). In this work, earthquakes were classified according to the period of occurrence in order to investigate the variation in the seismicity in the regions of study. The time intervals of 10 years (1981–1990), (1991–2000), and (2001–2010) were used. The number of earthquakes was recorded in each of the trenches. The histograms were also drawn for proper representation of number of earthquakes in each time interval (Figs. 12, 13, 14).

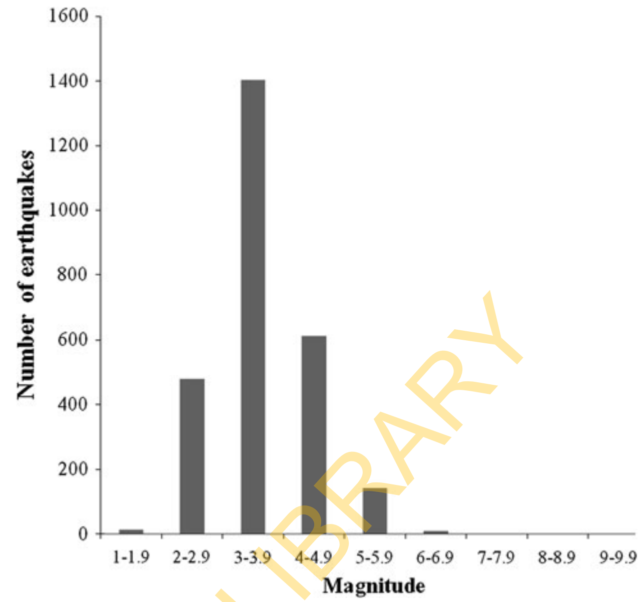

Fig. 3 Frequency–magnitude distribution of earthquakes along Peru–Chile Trench (1981–1990)

3 Results and discussion

The focal depth ranges of earthquakes in the three oceanic trenches studied were shown in (Fig. 2). Only few deep earthquakes that occurred were attributed with random focal depths ranging from 301 to 700 km (465 out of 37,139 earthquakes).

Shallow earthquakes were very prominent in all the trenches and they occurred at depth less than 70 km (29,541 out of 37,139 earthquakes). However, the intermediate earthquakes occurred with random focal depths ranging from 70 to 300 km (7,133 out of 37,139 earthquakes). This is in consonance with findings of Mishra et al. (2007a, b) in which occurrence of a large number of micro to moderate earthquakes at shallow layers were recorded during North Sumatra–Andaman region of the 2004 tsunamigenic earthquake earthquakes. This also demonstrated that crustal and sub-crustal stress

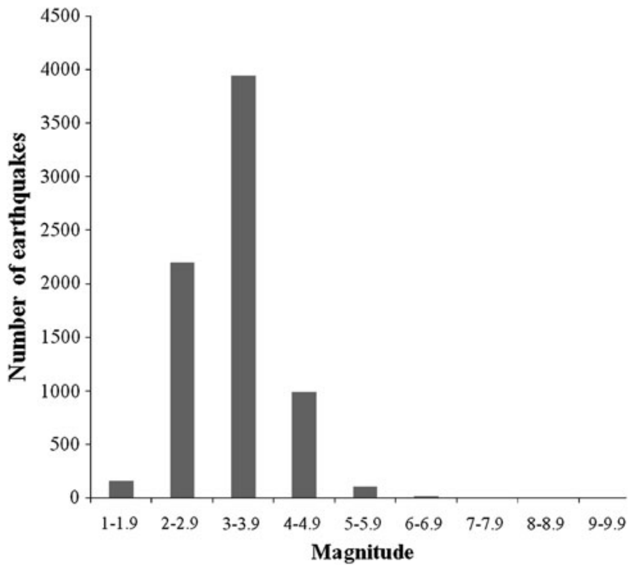

Fig. 4 Frequency–magnitude distribution of earthquakes along Peru–Chile Trench (1991–2010)

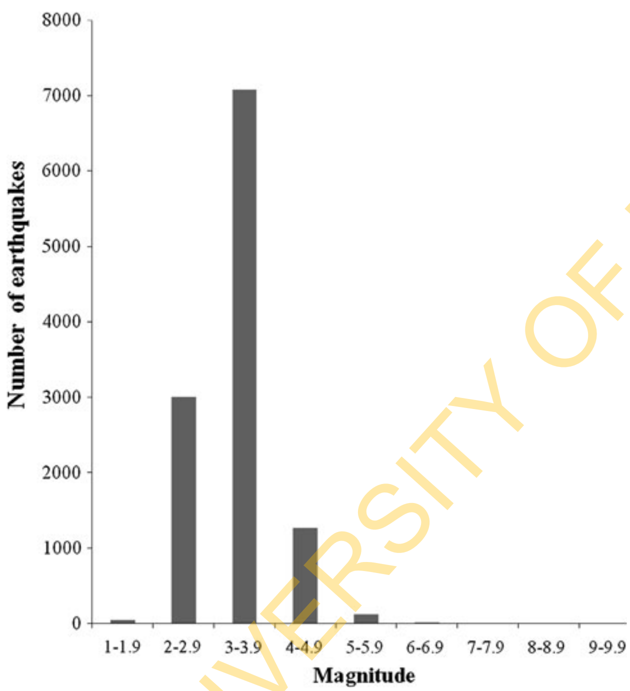

Fig. 5 Frequency–magnitude distribution of earthquakes along Peru–Chile Trench (2001–2010)

accumulation depends upon the number of earthquakes concentrating at a particular layer near the trenches.

Figures 3, 4, and 5, showed that the earthquakes in the Peru–Chile Trench were mostly of the magnitude 3.0–3.9. For the first decade (1981–1990), 2,655 earthquakes were recorded, the second decade (1991–2000), 7,356 earthquakes were recorded, the third decade (2001–2010), 11,525 earthquakes were recorded. This implies that there is

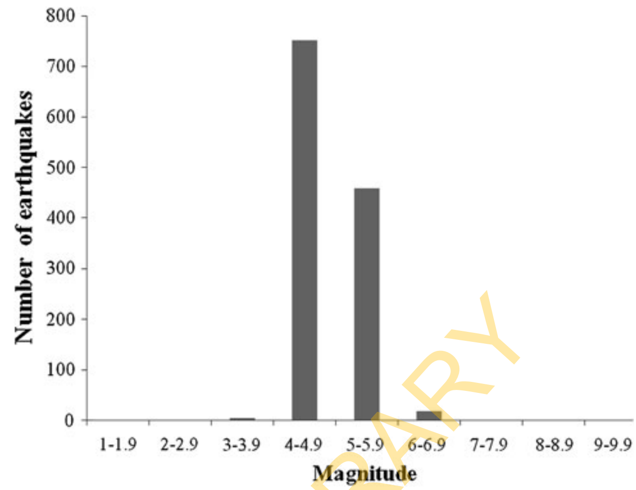

Fig. 6 Frequency–magnitude distribution of earthquakes along Japan Trench (1981–1990)

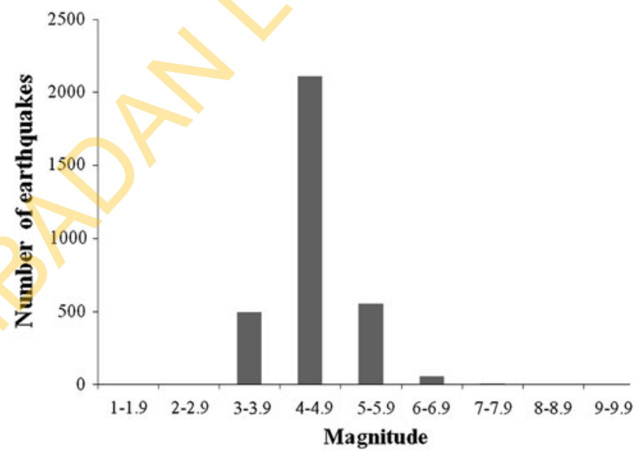

Fig. 7 Frequency–magnitude distribution of earthquakes along Japan Trench (1991–2000)

an increase in the total number of earthquakes for every decade in the Peru–Chile Trench.

The earthquakes associated with the Japan Trench were mostly of the magnitude 4.0–4.9 as shown in Figs. 6, 7, and 8. For the first decade (1981–1990), 1,235 earthquakes were recorded, the second decade (1991–2000), 3,226 earthquakes were recorded, the third decade (2001–2010), 4,147 earthquakes were recorded. This result showed that there is an increase in the total number of earthquakes for every decade in the Japan Trench.

Most of the seismic events in the Aleutian Trench were mostly of magnitude range 3.0–3.9 as shown in Figs. 9, 10, and 11. For the first decade (1981–1990), 1,107 earthquakes were recorded, the second decade (1991–2000), 2,804 earthquakes were recorded, the third decade (2001–2010), 3,084 earthquakes were recorded. This result showed that there is an increase in the total number of earthquakes for every decade in the Aleutian Trench.

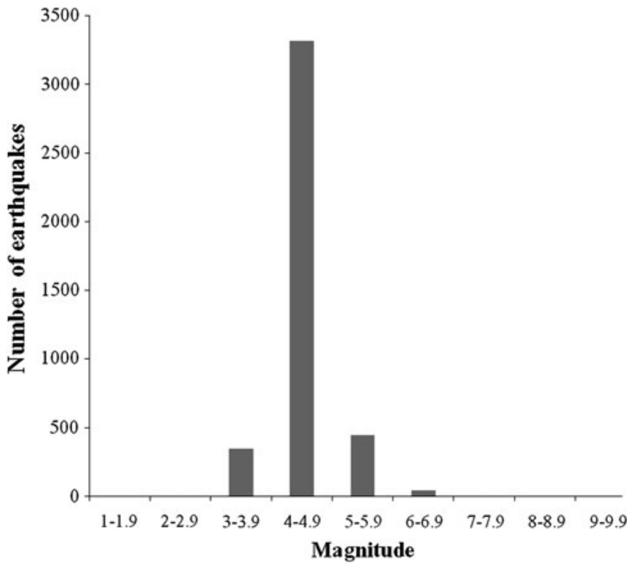

Fig. 8 Frequency–magnitude distribution of earthquakes along Japan Trench (2001–2010)

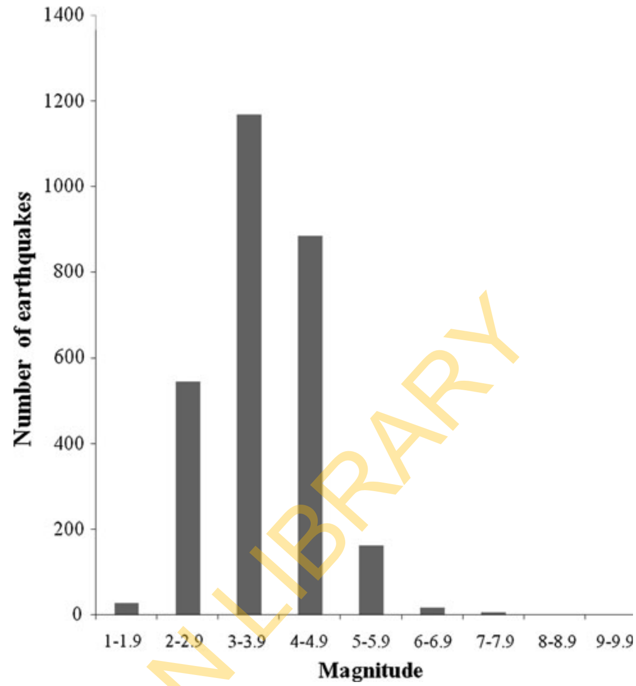

Fig. 10 Frequency–magnitude distribution of earthquakes along Aleutian Trench (1991–2000)

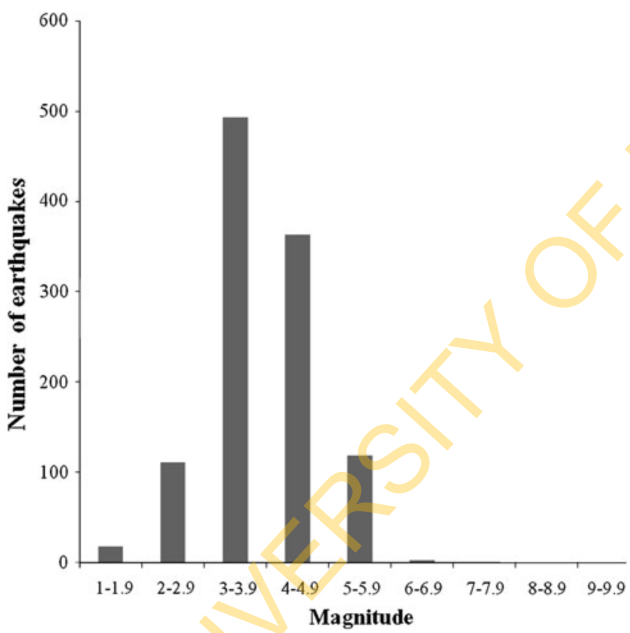

Fig. 9 Frequency–magnitude distribution of earthquakes along Aleutian Trench (1981–1990)

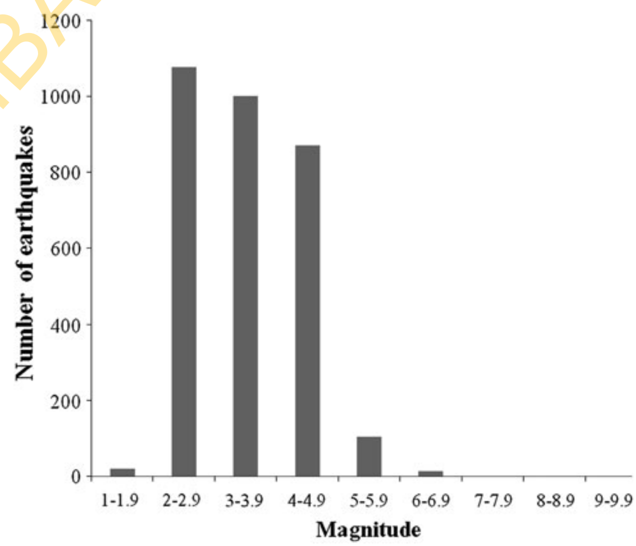

Fig. 11 Frequency–magnitude distribution of earthquakes along Aleutian Trench (2001–2010)

Frequency distribution of earthquakes in each decade at each of the trenches was shown in Figs. 12, 13, and 14. The results revealed that the occurrence of earthquakes increased with time in all the three oceanic trenches. This showed that the relative motion between the lithospheric plates was increasing with time which led to the large accumulation of tectonic stress. This increase in earthquakes with time can also be linked with the increasing detectability of the seismic network. With the increasing detectability, more earthquakes of small magnitudes were detected and recorded.

Comparison of the earthquakes in the three trenches for three decades (1981–2010) (as shown in Fig. 15) revealed that the largest number of earthquakes was embedded in the Peru–Chile Trench. Thus, the seismic events were more

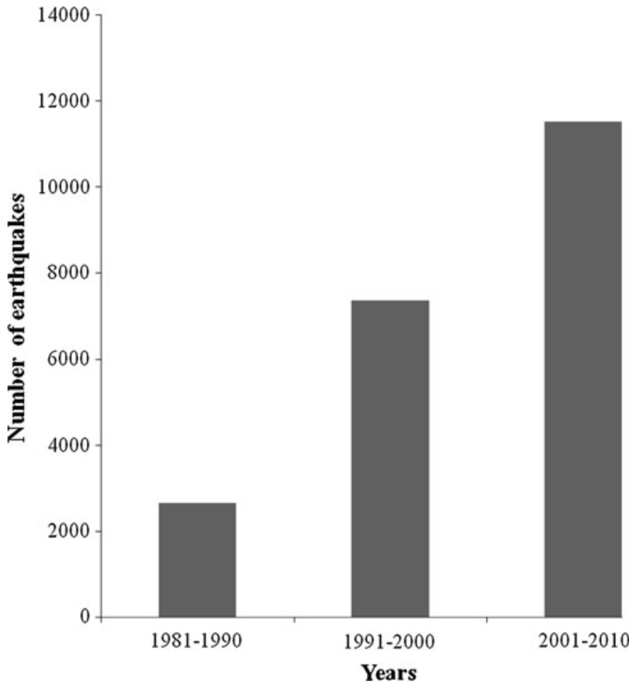

Fig. 12 Frequency distribution in each decade along Peru–Chile Trench

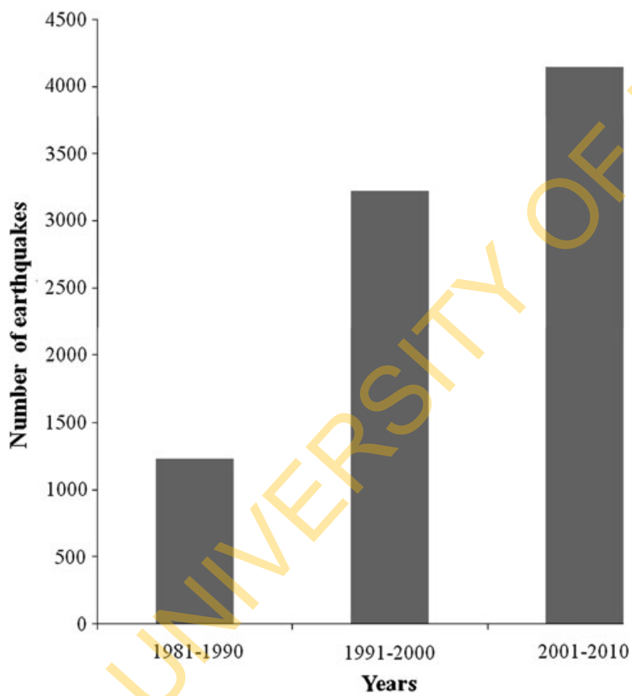

Fig. 13 Frequency distribution in each decade along Japan Trench

pronounced at Peru–Chile Trench than other trenches. This implies that the lithospheric plates associated with the Peru–Chile Trench are very unstable. Hence, the seismic activity will continue to be increasing rapidly in Peru–Chile Trench.

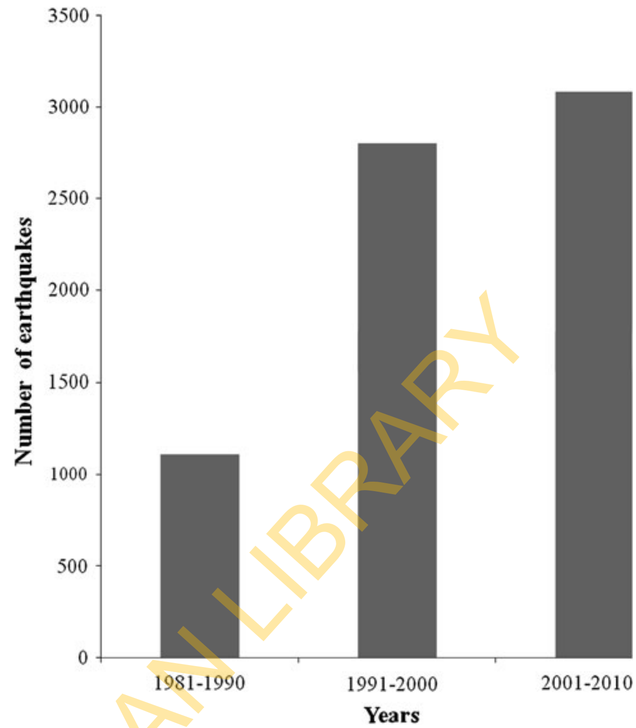

Fig. 14 Frequency distribution in each decade along Aleutian Trench

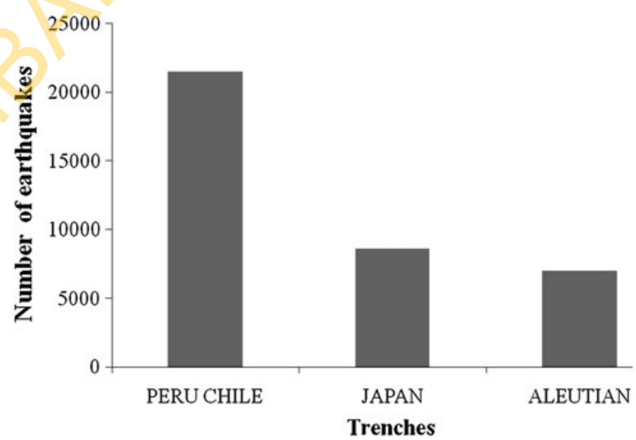

Fig. 15 Frequency distribution of earthquakes for three decades (1981–2010)

4 Conclusions

Due to the increase in earthquakes with time in all the oceanic trenches studied, the lithospheric layer is becoming more unstable and tectonic stress accumulation is increasing with time. The seismic events were more pronounced at Peru–Chile Trench than other trenches. This revealed that the oceanic lithospheric plates that embedded Peru–Chile Trench are very unstable. Hence, the seismic activity will continue to be increasing rapidly in Peru–Chile Trench. The magnitude range in the oceanic trenches provided faulting mechanism that can displace a huge column of water beneath the ocean.

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