VARIATION OF b – VALUE IN THE EARTHQUAKE FREQUENCY – MAGNITUDE DISTRIBUTION WITH DEPTH IN THE INTRAPLATE REGIONS

Emad A. M. AL- Heety
Department of Applied Geology – University of Anbar
Ramadi – Iraq
Email : ealheety@yahoo.com

Abstract

We map the earthquake frequency – magnitude distribution (b value) as a function o depth in the intraplate regions of the earth. About 590 well – located events in the different intraplate regions are selected for this analysis. The earthquake data sets are separated in 10 km zones from 0 to 40 km depth. The b-value of the intraplate regions ranges from 0.72 to 1.20. There is a clear tendency for decrease in b- value in Africa, Asia, North America and Globally, and increase in b-value in Australia and Europe . The low b-values and low seismicity at depth range of 20-30 km may be associated with low degree of heterogeneity and high rheological strength in the Crust. The result shows that the b-value increases below the depth range of 20-30 km in Africa, Asia, North America and Globally and decreases in Australia and Europe. We found that there is high seismicity below the depth range of 20-30 km. Such high seismicity with high b-values may be associated with high heterogeneity as well as with low strength in the crust.

Key words : Intraplate earthquakes; Frequency – magnitude relation; b-value; Seismicity.

I. INTRODUCTION

In the mid1950's , Gutenberg and Richter [1] introduced a formula for the frequency – magnitude distribution (FMD), in the form :

$$\text{Long } N = a - b\,M \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

For a certain region and time interval, eq.(1) provides the 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 certain region depends upon the volume and time window considered. The **b** parameter is a tectonic parameter that seems to represent properties of the seismic medium. After the pioneering works of [2], [3] [4], they have been extensively used by other workers. The temporal variation of **b** was investigated by many researchers (e.g. [5], [6], [7]. The relations between **b**- value and a physical properties such as stress, material homogeneity and pore pressure were studied by other authors (e.g. [2], [3] [4], [8]). Studies investigating the spatial variation of b-value were carried out by many workers (e.g. [2], [3] [4], [8]). Studies investigating the spatial variation of **b**-value were carried out by many workers (e.g. [9], [10], [11], [12]).

Gutenberg and Richter [1] suggested that the b parameter changes between 0.45 and 1.5, while Mogi [2] found that **b**-value ranges from 1.0 – 1.6 for the global seismicity. For global seismicity, McNally [13] found that the **b**-values range between 0.8 – 1.2, and Udias and mezcua [14] found that the **b**-values range from 0.6 to 1.5 for the global seismicity. Monerroso and Kulhanek [15] found that the b-values range from 0.6 to 1.6 for Central America seismicity.

Few studies investigated the variation of b-value with the depth. Gutenberg and Richter [1] found that values of **b** are 0.90 ±0.02, 1.2±0.2 and 1.2±0.2 for shallow, intermediate and deep earthquakes, respectively. Depth dependence of **b**-values may reflect the degree of material heterogeneity [2] and stress conditions [3]. Some investigators [16],[17],[18] have shown that increasing of pressure with depth, as possible, leads to decrease of b-value with depth, in general. Mori and Abercrobie [19] investigated the variation of **b**-value with depth in California, and found that there is a systematic decrease in b-value with the increasing depth of earthquakes. To explain the observation, they postulated that due to the high heterogeneous material properties and low lithostatic stress at the shallow crust (0-6km), rupture initiations are more likely to stop before growing into larger earthquakes, producing more smaller earthquakes.

ZHU et al [20] investigated the variation of the **b**-value with depth in Beijing area. The results show that the **b**-values decrease with increasing the hypocentral depth, systematically. A dramatic variation in **b** is observed around the depth of 8km.

It indicates that there are more smaller earthquakes at shallow depth(0-8km),while more larger earthquakes occur at greater depth(8-25km). The physical mechanism behind this phenomenon can be explained by the variations in material heterogeneity, an lithostatic stress condition. Khan and Chakraborty [21] found that the high b-values associated with depth, coinciding with the lower crust, indicate that the shilling Plateau , India , is supported by a strong lithosphere. Amorèse et al [22] found that the variability of **b** is often not statistically significant and that the decrease of **b** with depth should be interpreted with caution. Singh and Chadha [23] found that there is a systematic decrease in **b**-value up to 8km followed by an increase in the Koyna-Warna, India. The increase in b-value is interpreted in terms of presence of the fluids.

Low b-value areas at 5km depth indicate localized high stresses which are favorable for future rupture. The purpose of this study is to investigate the variation of b-value with depth in the intraplate regions.

II. b-Value in the Intraplate Regions

Many investigators estimated the b-value in the intraplate regions, locally, regionally and globally. According to Talwani [24], the low **b**-value is a characteristic feature of the intraplate regions. One possible explanation for this observation is that within the plate the rocks are not as intensively fractured. Triep and Sykes [25] found that for all active intracontinental regions combined, except Asia, **b**- value changes from 0.90 to 2.1 at a corner magnitude Mc of 6.9 to 7.0. The distribution of stable regions indicates similar changes. The **b**-value for Australia is 0.88 [26]. The **b**-value for the entire Indian Peninsula is 0.92 [27],[28]. From historical earthquakes, Al-Heety [29] estimated the b-value of the stable continental regions in the Arabian plate. It equals to 0.47. Stein and Newman [30] found that the New Madrid Seismic Zone has **b**-value equals to 0.91. In the Wasbash Zone , the **b**-value equals to 0.74. The parameters of the Gutenberg-Richter in Mumbia City, India, are **a** = 7.7 ± 0.04 and **b** = 0.86 ± 0.02 [31]. Al-Heety and Eshwehdi [32] studied seismicity of the northwestern region of Libya as an example of continental seismicity. The b-value of this region equals to 0.73 ± 0.038. The b-value of the western desert of Iraq is 0.54 [33]. Okal and Sweet [34] conclude that both ***ß*** – and **b**-values for true intraplate earthquakes are essentially equivalent to those of interplate earthquakes in similar ranges of moments or magnitudes.

III. Data

The source catalogs for the database of our study are the catalog of shallow intraplate earthquakes [35], the EPRI earthquake data sheets [36] and the earthquake catalog for stable continental regions [37]. An earthquake data set used in seismicity or seismic studies must be homogenous and complete. All earthquake magnitudes should be in the same magnitude scale and a specific time period. A uniform magnitude scale, the moment magnitude M_w ,was applied throughout the catalog. The $M_w = 2/3 \log M_0 - 10.7$ [38], where M_0 is the seismic moment(in dyne.cm).For those events where M_0 was not available, it was determined from regressions of M_0 on other magnitude scales(mb, Ms), which had already been developed for [36].The Spatial distribution of earthquakes in the studied regions is shown in **Fig 1**. The events that lack the magnitude and focal depth were excluded.

IV. Methodology and Results

The estimation of the magnitude of completeness (Mc) is critically important in calculating b-values [39]. A forward modeling technique proposed by Wiemer and Wyss [39] is used to calculate the

Mc. Mc is obtained as 4.5. Five hundred and ninety earthquakes larger than M_w 4.5 used to estimate the b-values.This number changes from region to other (Table 1).

The Maximum-Likelihood method was used to estimate the b-value in the frequency-magnitude relation [40] :

$$ß= \log_e /(M_{av} - M_{min}) = 0.43/(M_{av} - M_{min}) \ldots\ldots\ldots\ldots (2)$$

Where M_{av} is the mean of the observed magnitude and M_{min} is the minimum or threshold magnitude in the group of events for complete reporting. With 95% of confidence limit, the overall b-values are 0.90 ± 0.06, 0.84 ± 0.08, 0.99 ± 0.08, 1.2 ± 0.15, 0.72 ± 0.07, and 0.90 ± 0.03 for Africa, Asia, Australia, North America, and the Globe, respectively. The data were divided into four groups based on the depth ranges of 0-10, 10-20, 20-30 and 30-40 km to calculate b-values (Table 1 and **Fig.2**). An overlap depth of 10 km (moving step) was used to maintain the inherent continuity of the data points. To ensure the stability of the b-value estimations independent of the method used, the least square method (LS) was also applied to calculate the b-values for the above depth ranges and results are shown in Table 2. The results from both methods show the consistent tendency of decrease in b-values with increasing hypocentral depth. The results showed decreasing of b – value increasing depth to the depth range (20 – 30km) in Africa, Asia, North America and Globally and increasing of b – value with increasing of depth in Australia and Europe (**Fig. 2**).Below the depth range (20 – 30Km), there exists increase in b – value in Africa, Asia, North America and Globally and decrease of b – value in Australia and Europe. **Fig.3** illustrates the depth distribution of seismicity in the all intraplate regions. Irrespective of the b-values, it was found that in all the regions the lowest seismic concentrations are observed between 20 and 30 km.

V. Discussion

Previous studies show that the main factors that can cause perturbations of the normal b-values are material heterogeneity, effective stress and temperature [2],[3],[4] ,[41]. High b-values indicate a large number of small earthquakes, to be expected in regions of low strength and large heterogeneity, whereas low values indicate high resistance and low heterogeneity [42], [43],. The phenomenon of heterogeneity decreases with depth and normal stress has long been noted [44]. The b-value may also decrease with increasing depth [19],[5] possibly due to increasing applied stress at deeper levels [45]. It is reasonable to consider that the physical mechanism behind the decrease in b-value with increasing depth can be explained by the variations in material heterogeneity and lithostatic stress conditions.

Because of the intraplate earthquakes are infrequent, the access to a sufficient number of shocks by more than 4.5 meets the requirements of statistical analysis on the calculation of b – value variation with focal depth, is impossible. Studies show that most earthquakes of this type occurs in the upper crust [25], [46] . we find that the number of earthquakes in the depth ranges in excess of 20 km will be few. According to the above mentioned, variation of b – value is often not statistically significant and that conclusions of this study must be taken with caution.

The low b-values and low seismic activity at depth 20-30 km (**Fig.2 and Fig.3**) can be accounted for by a low degree of heterogeneity and high rheological strength in the crust, allowing brittle failure at higher levels of stress. The high b-values and high seismic activity following the depth 20-30 km (**Fig.2 and Fig.3**) reflect a sharp change in the subsurface rheology. Such a high seismicity, with high b-values may be associated with high heterogeneity as well as with low strength in the crust.

VI. Conclusions

From our study, we conclude the following:

1. The b-value of the intraplate regions ranges from 0.72 ±0.07 to1.20 ±0.0.15. Globally, b-value is 0.90 ± 0.03.
2. There is a clear tendency for decrease in b-value with depth in Africa Asia, North-America and Globally, and increase in b – value in Australia and Europe.
3. The low b-values and low seismic activity at depth 20 – 30 km may be associated with low degree of heterogeneity and high rheological strength in the crust.
4. There are increases in b-value below the depth range of (20 – 30 km) in Africa, Asia, North America and Globally and decrease in Australia and Europe . There is high seismicity below the depth range of (20 – 30 km). Such high seismicity with high b-values may be associated with high heterogeneity as well as with low strength in the crust. .

VII. References

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Table 1: Variation of b – value with depth in the intraplate regions of the continents

Region	Depth Range (Km)				
	0 - 10	10 - 20	20 - 30	30 - 40	For all
Africa	N = 107 M_{min} = 4.5 b = 1.26 ± 0.12	N = 28 M_{min} = 4.5 b = 1.0 ± 0.18	N = 8 M_{min} = 4.5 b = 0.59 ± 0.20	N = 54 M_{min} = 4.5 b =1.12± 0.15	N = 197 M_{min} = 4.5 b = 0.90 ± 0.06
Asia	N = 27 M_{min} = 4.5 b = 0.82 ± 0.15	N = 8 M_{min} = 4.5 b = 0.78 ± 0.18	N = 16 M_{min} = 4.5 b = 0.71 ± 0.21	N = 37 M_{min} = 4.5 b =1.19 ± 0.19	N = 88 M_{min} = 4.5 b = 0.84 ± 0.08
Australia	N = 58 M_{min} = 4.5 b = 0.81 ± 0.10	N = 25 M_{min} = 4.5 b = 0.81 ± 0.16	N = 4 M_{min} = 4.5 b = 1.56 ± 0.76	N = 56 M_{min} = 4.5 b =1.03 ± 0.13	N = 143 M_{min} = 4.5 b =0.99 ± 0.08
Europe	N = 30 M_{min} = 4.5 b =1.14 ± 0.20	N = 11 M_{min} = 4.5 b =1.19 ± 0.35	N = 8 M_{min} = 4.5 b = 1.43±0.50	N = 13 M_{min} = 4.5 b =1.07 ± 0.28	N = 62 M_{min} = 4.5 b = 1.20 ± 0.15
North America	N = 49 M_{min} = 4.5 b = 0.91 ± 0.13	N = 32 M_{min} = 4.5 b = 0.86 ± 0.17	N = 8 M_{min} = 4.7 b = 0.60 ± 0.21	N = 11 M_{min} = 4.5 b = 0.68 ± 0.20	N = 100 M_{min} = 4.5 b = 0.72 ± 0.07
Globe	N = 271 M_{min} = 4.5 b = 0.92 ± 0.07	N = 104 M_{min} = 4.5 b = 0.89 ± 0.12	N = 44 M_{min} = 4.5 b = 0.74 ± 0.14	N = 171 M_{min} = 4.5 b = 1.1 ± 0.08	N = 590 M_{min} = 4.5 b = 0.90 ± 0.03

N = Number of events M_{min} = Minimum magnitude

Table 2: The b- values for a depth ranges using different estimation methods

Region	Method	Depth range (km)			
		0 – 10	10 – 20	20 – 30	30 – 40
Globe	ML: LS :	0.92 ± 0.07 1.06 ± 0.04	0.89 ± 0.12 1.0 ± 0.07	0.74 ± 0.14 0.92 ± 0.04	1.1±0.08 1.35 ± 0.05

ML, The maximum likelihood estimation ; **LS**, the least squares estimation.

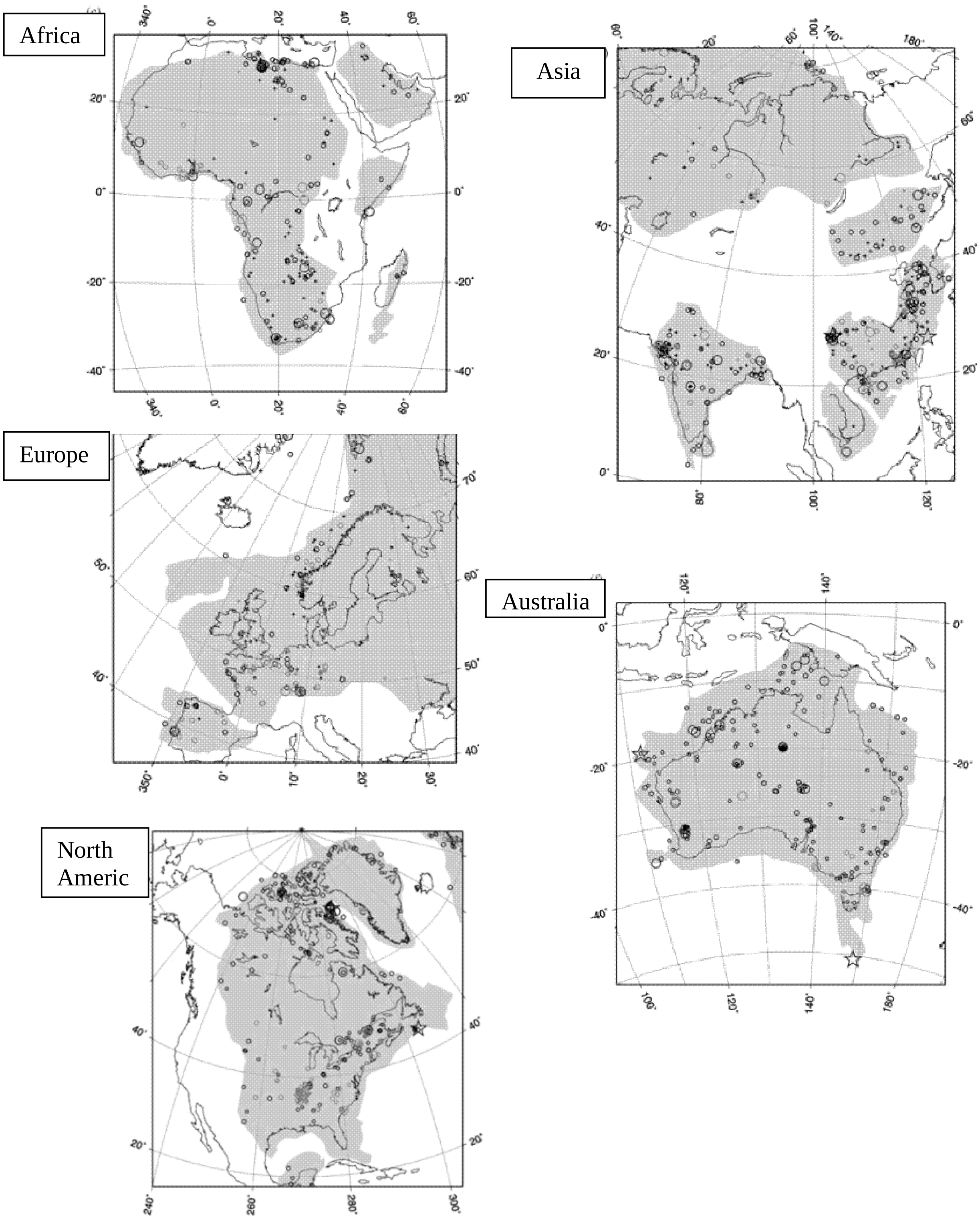

Figure 1: Spatial distribution of intraplate events in the different intraplate regions. Instrumental earthquakes are denoted by dark grey circles, historical earthquakes by light grey circles. Stars indicate M = 8 events. In Africa and Asia, crosses are smaller (4.5 – 5) events.(After Schulte and Mooney, 2005).

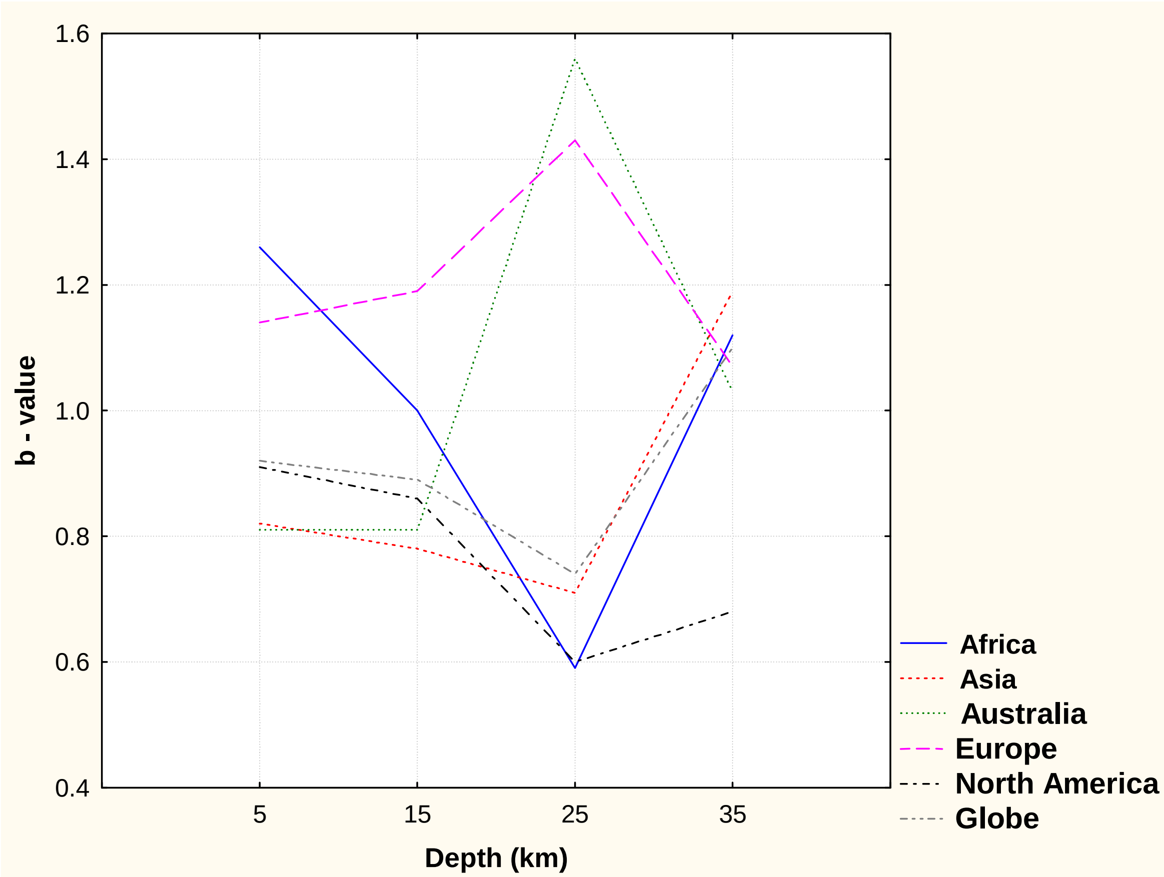

Figure 2: Depth variation of b – value for different intraplate regions in the continents and globally.

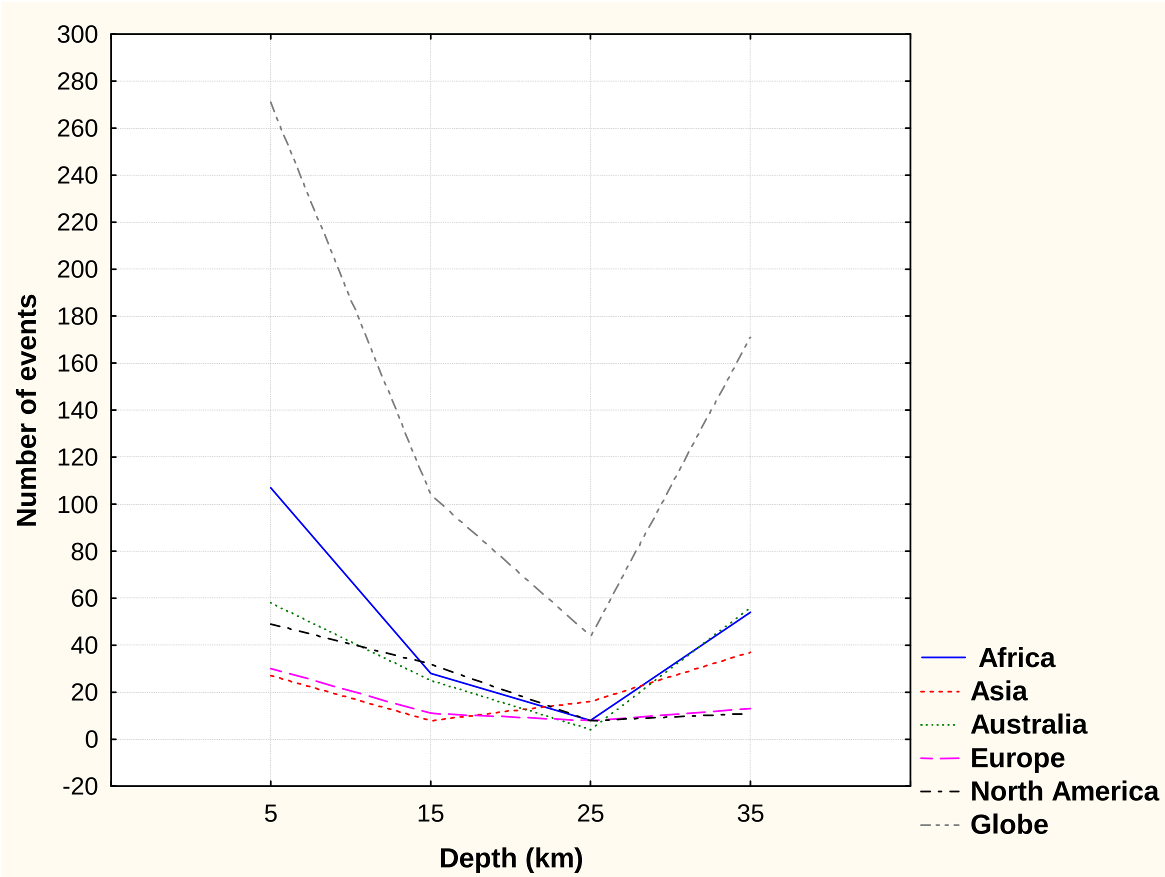

Figure 3:
Variation of seismicity with depth for the intraplate regions in the continents and globally.