UTRIP 2021 REPORT

Title: The Distribution of B-value Around Japan

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Introduction

Japan is one of the most tectonically active regions in the world. It is situated along the Pacific Ring of Fire with four tectonic plates surrounding the island (Figure 1a).

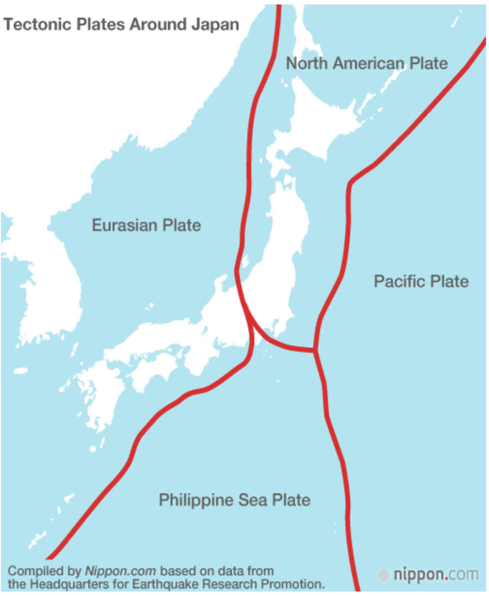


Figure 1a

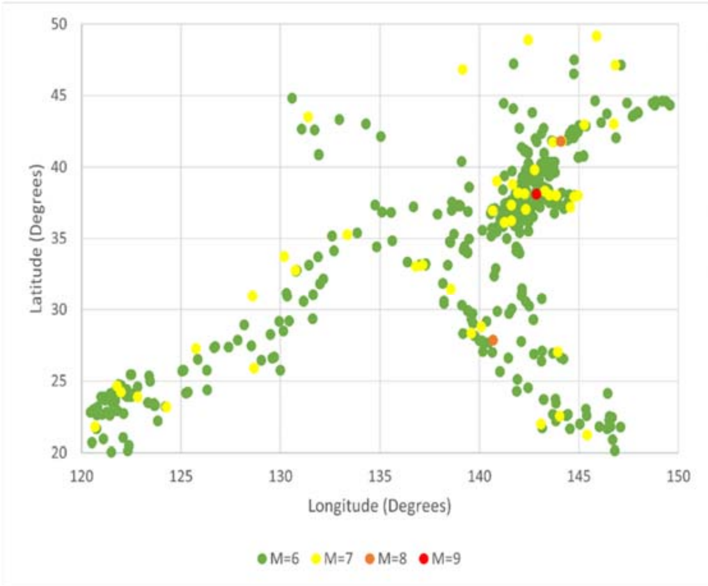


Figure 1b

The movement and collision of these tectonic plates against each other built stress over time. This stress is then released through destructive earthquakes that have taken the lives of millions since historical earthquakes were recorded.

The strongest earthquake in the island occurred over a decade ago with magnitude 9.1 due to the subduction of the Pacific Plate beneath the Okhotsk Plate. A map of the earthquake distribution around Japan since the year 2000 to 2021 from the Japan Meteorological Agency's earthquake catalogue is shown in Figure 1b.

In this study, we will be examining the distribution of earthquakes not just around the whole Japanese Island, but also at different seismic domains: Nankai Trough, Izu-Bonin, Japan, Ryukyu, and Kuril trench. We selected the trenches as the scope of our study because they were formed as a result of the convergence of plate boundaries and are thus more prone to cause powerful, deep-focus earthquakes.

Along Northwest Japan, both the Japan and Kuril Trench were created as the result of the subduction of the Pacific Plate beneath the Okhotsk Plate. The Philippine Sea Plate subducts underneath the Eurasian Plate along Ryukyu Trench and Nankai Trough. Meanwhile, for Izu-Bonin Trench, the Pacific Plate subducts under the Philippine Sea plate.

The distribution of earthquakes around Japan as well as the trenches will be examined according to the Gutenberg-Richter law

$$\log N(M) = a - bM \quad (1)$$

Where N is the cumulative number of earthquakes with magnitude equal or greater than M, while a is the general level of seismicity in the area and b is the relative earthquake size distribution. A high b-value corresponds to a high number of small earthquakes; conversely, a low b-value shows the predominance of large earthquakes over smaller events in a certain region. The law has been widely used by seismologists for probabilistic earthquake hazard assessments

Methods

In Microsoft Excel, the b-value for the whole of Japan was determined using the least squares method by first making a pareto chart (Figure 2a) based on the earthquake magnitudes. Then, the cumulative data obtained was arranged into a scatter plot to produce an exponential curve. The curve was linearized into a straight line as shown in Figure 2b. Calculations were then performed to determine the gradient of the straight line. The calculation for b-value of Japan is shown below.

From the eqaution in Figure 2b,

$$y = (5 \times 10^7)e^{-2.056x}$$

Linearizing the equation,

$$\log y = \log(5 \times 10^7) + \log(e^{-2.056x})$$

$$\log y = \log(5 \times 10^7) - 2.056\text{x}\log(e)$$

$$\log y = 7.6989 - 0.8929\, x$$

This takes the same form as the Gutenberg-Richter law. From (1),

$$\log N(M) = a - bM \quad (1)$$

Thus,

$$b = 0.8929 \pm 0.0252$$

We verified the b-value estimation using the LINEST() function in Excel which also gives us the uncertainty of the slope and hence, the uncertainty of the b-value itself.

The data was further analyzed to determine the b-value for each seismic domains: Nankai Trough, Izu-Bonin Trench, Japan Trench, Ryukyu Trench, and Kuril Trench. We selected the data based on the latitude and longitude, as shown by the black rectangles in Figure 2 which represent the cross-section area of each region.

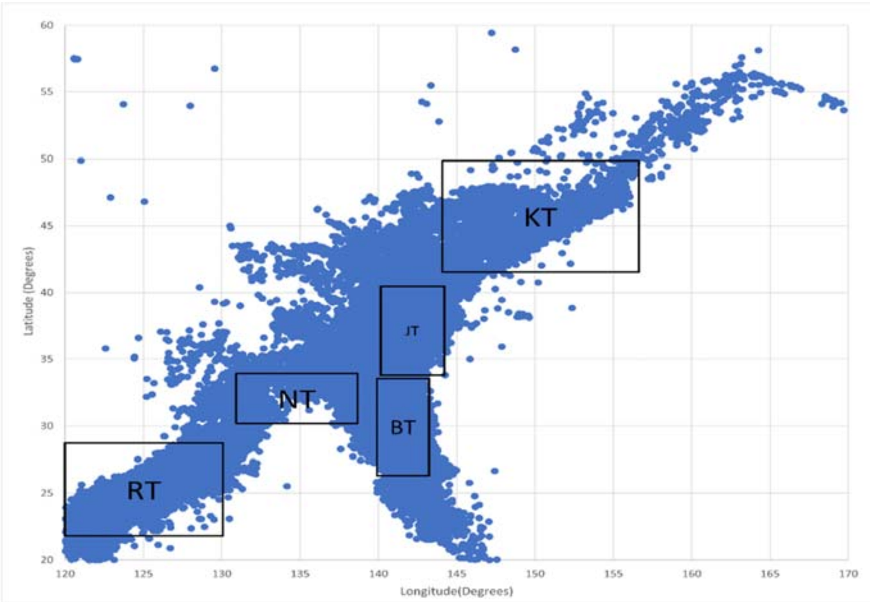


Figure 2

The area of each domain is as follows:

a. Nankai Trough: From 30°N, 132°E to 34°N, 138°E
b. Izu-Bonin Trench: From 26°N, 140°E to 34°N, 143°E
c. Japan Trench: From 34°N, 140°E to 40°N, 145°E
d. Ryukyu Trench: From 22°N, 120°E to 27°N, 130°E
e. Kuril Trench: From 41°N, 144°E to 50°N, 156°E

Then, we repeated the similar procedures as with the previous analysis (for whole Japan). A pareto histogram for each region was made as shown in Figure 4(a) to 4(e). Accordingly, calculations to determine the b-value for each distribution were performed as included in the Appendix section.

Results

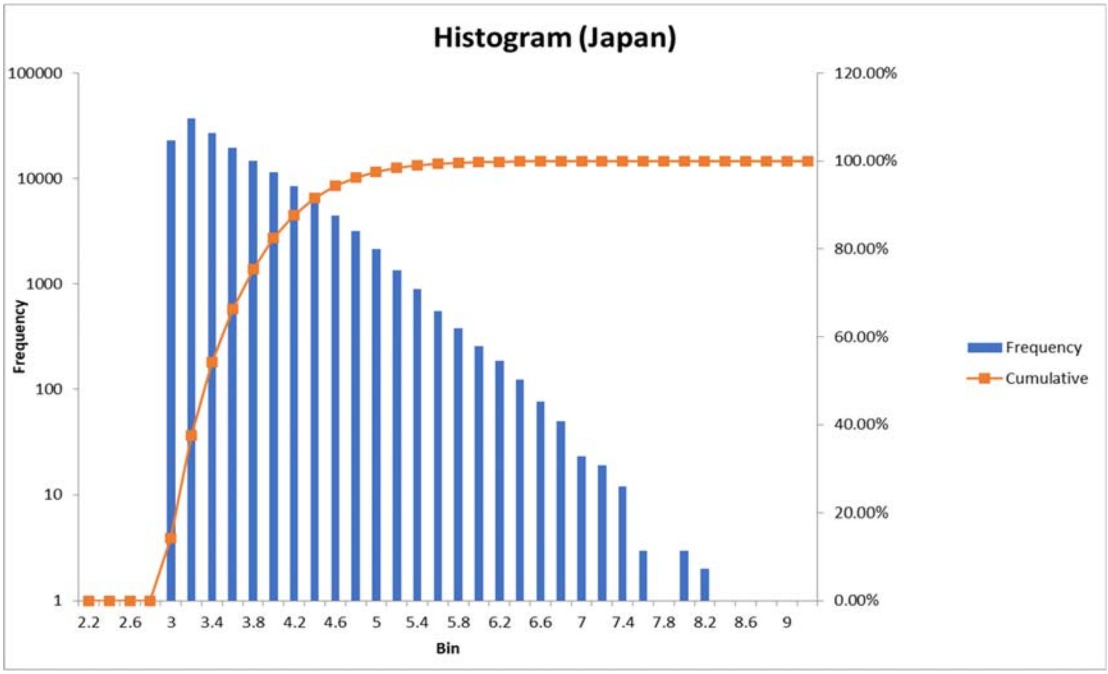


Figure 2a

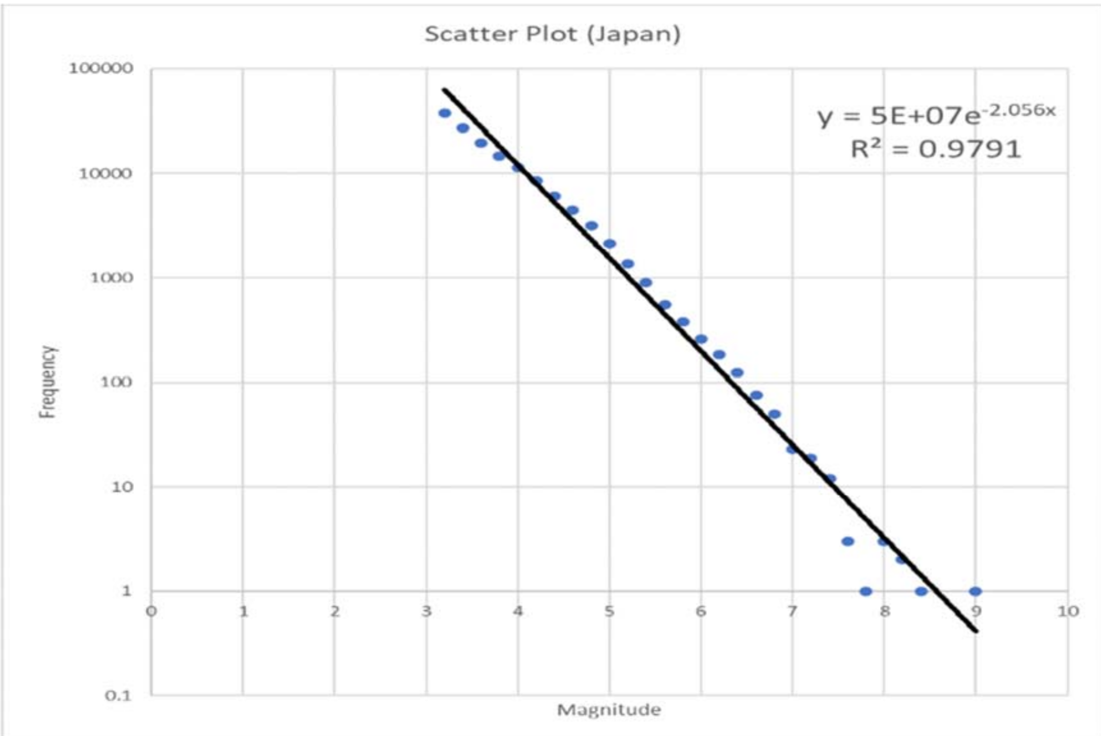


Figure 2b

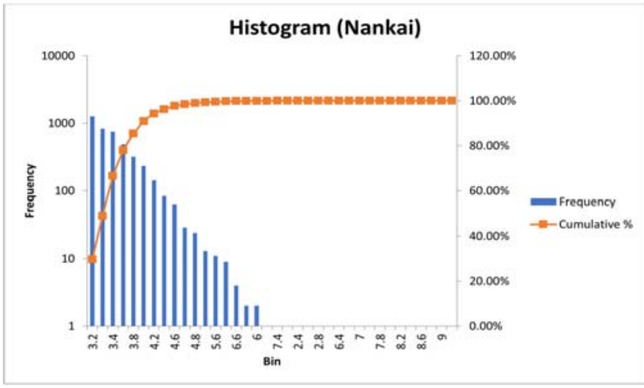


Figure 4a

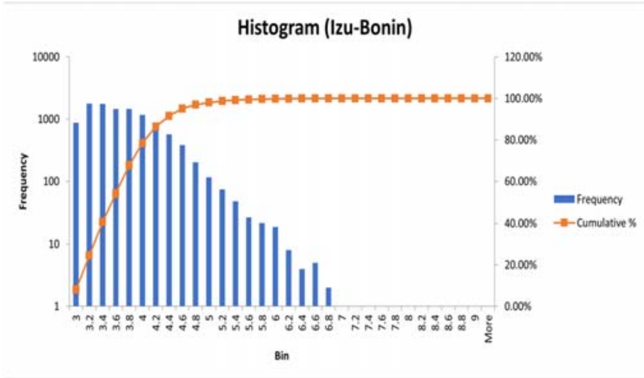


Figure 4b

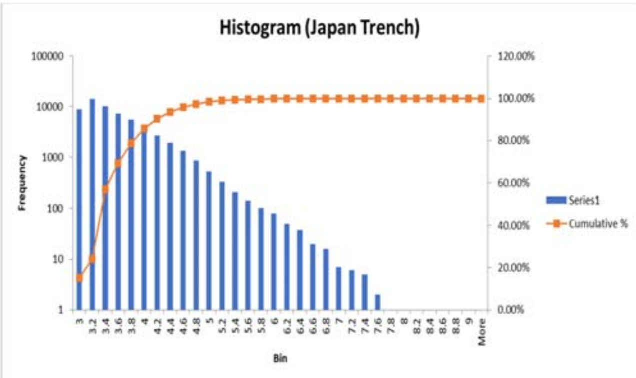


Figure 4c

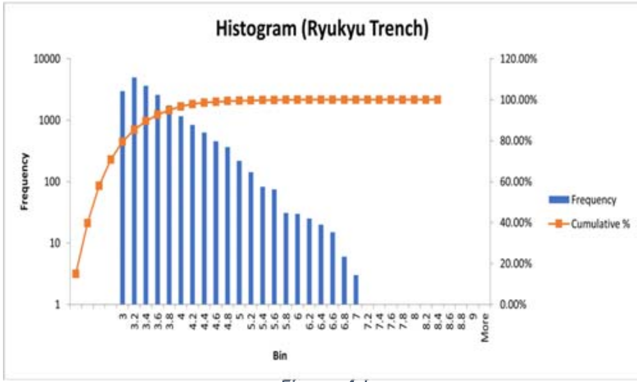


Figure 4d

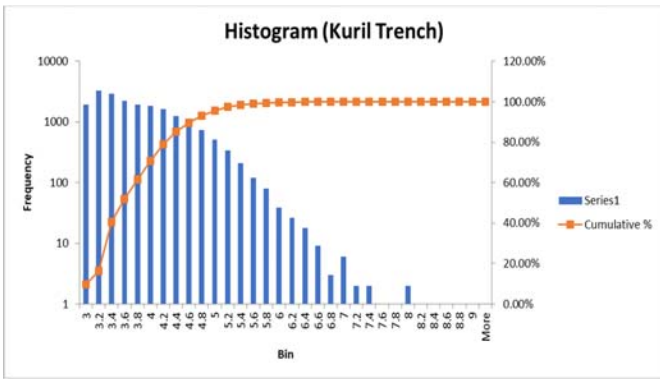


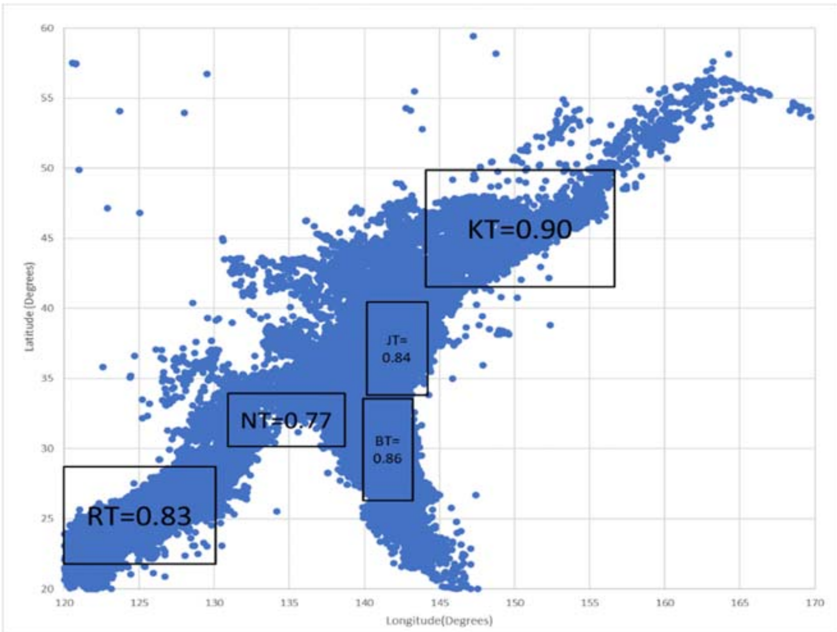
Figure 4e

Discussion & Conclusion

This study revealed that the Gutenberg-Richter b-value for Japan is $b = 0.89 \pm 0.03$. The high b-value which is close to 1 indicates that small earthquakes occur more frequently than large earthquakes throughout the island and its surroundings.

Since the seismicity in Japan is quite diverse in tectonic setting, further analysis was carried out to determine the b-value for some trenches around the Japanese archipelago. The b-values are shown in the table below:

Domains	**B-value**
Whole Japan	0.8929 ± 0.0252
Nankai Trough	0.7674 ± 0.0467
Izu-Bonin Trench	0.8573 ± 0.0489
Japan Trench	0.8121 ± 0.0210
Ryukyu Trench	0.8265 ± 0.0277
Kuril Trench	0.8990 ± 0.0563



As illustrated above, the b-values are similar to each other for all the tested cases except Kuril Trench and Nankai Trough. Interestingly, the b-value for the whole of Japan is slightly larger than each of the seismic domains. However, Kuril Trench is also an exception to this since the b-value obtained is a bit higher than that of whole Japan.

According to Schorlemmer et. al (2005), regions where normal faulting occurs at the plate boundary have higher b-value compared to thrust faults which correlate to a lower b-value. Meanwhile, strike-slip faults showed evidence of moderate b-value.

This prompts us to compare the tectonic settings of each domain with the b-value obtained. Thrust faults predominate Nankai Trough, Japan Trench and Izu-Ogasawara arc. Normal faults are the main focal mechanism along Ryukyu Arc. Therefore, Japan Trench, Nankai Trough and Izu-Bonin trench should obtain low b-values whereas Ryukyu Trench should produce a high b-value.

This is in line with our results whereby we obtained high b-value for Ryukyu Trench (0.83) and low b-value for Nankai Trough (0.77). However, Japan and Izu-Bonin Trench also yielded moderate to high b-values, which is incongruent with the expected outcome.

Among all the regions, Kuril Trench has the highest frequency of low magnitude earthquakes as shown by the b-value obtained. The oblique subduction of Kuril Trench which results in normal and strike-slip faulting may provide an explanation for this observation.

Scholz (2015) found that the b-value for earthquake decreases linearly with stress at subduction zones. As such, our results may present evidence that stress is lowest along Kuril, followed by Izu-Bonin, Japan, and Ryukyu Trench and highest in Nankai Trough.

The low b-value and high differential stress along Nankai Trough may be correlated to slow-slip events which has been observed in this region, as described by Nanjo and Yoshida (2018) as well as Chiba (2020).

However, the findings in this investigation may not give an accurate assessment of the state of stress at each subduction zones. A more detailed approach targeting each plate boundary region such as by Nanjo & Yoshida (2018) could provide a deeper look into the stress at the trenches.

Furthermore, a better and more robust estimate of the b-value could also be produced by using the Maximum Likelihood Method or by comparing the b-values obtained for a certain region using data from different catalogues.

With that being said, we managed to fulfill the objectives of this study which is to determine the b-value of Japan and the trenches surrounding the island. The b-value of Japan is 0.89 which shows that there is the predominance of small earthquakes throughout the country. The highest b-value among the trenches is Kuril Trench, followed by Izu-Bonin, Ryukyu, Japan and finally Nankai Trough.

References

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   https://doi.org/10.1186/s40623-020-1130-7
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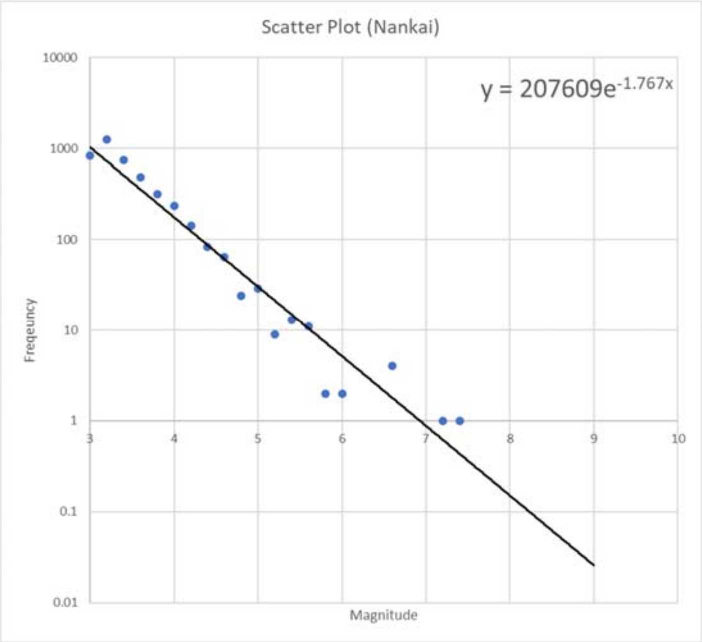
4. Scholz, C. H. (2015). On the stress dependence of the earthquake b value. *Geophysical Research Letters*, *42*(5), 1399-1402.
5. Schorlemmer, D., Wiemer, S., & Wyss, M. (2005). Variations in earthquake-size distribution across different stress regimes. *Nature*, *437*(7058), 539-542.

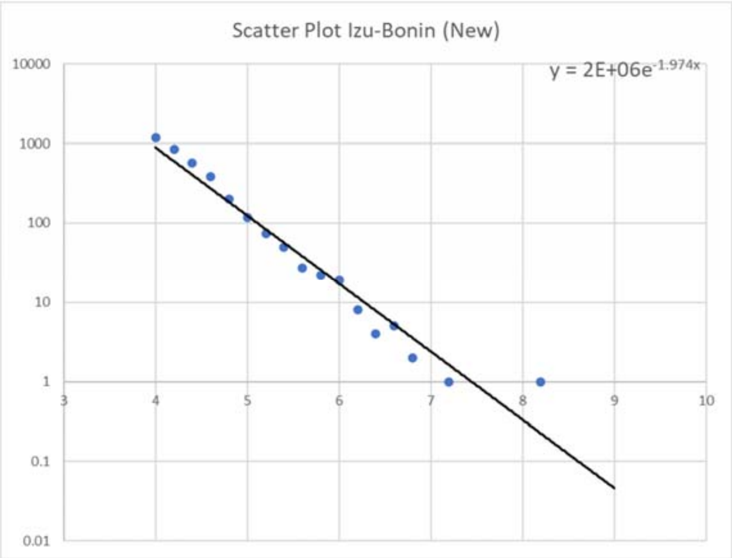
Appendix: Calculation of B-values

a. B-value Nankai Trough



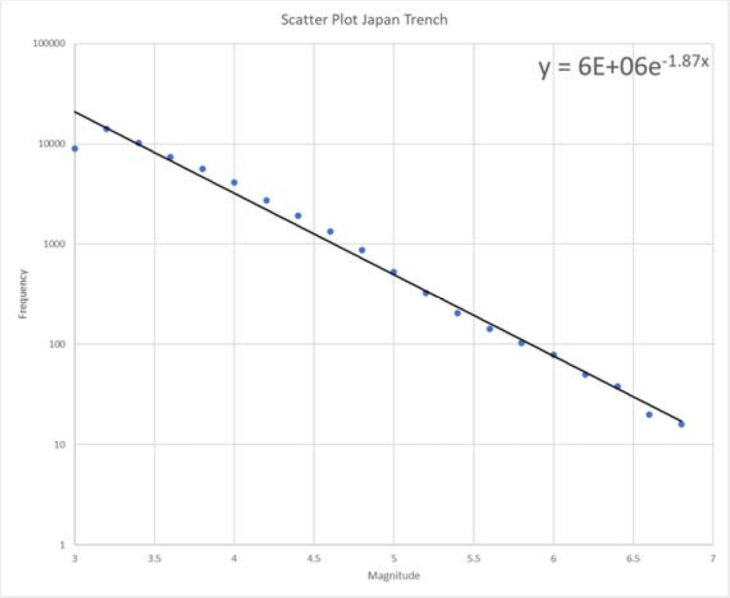
$$y = (207609)e^{-1.767x}$$
$$\log y = \log(207609) + \log(e^{-1.767x})$$
$$\log y = \log(207609) - 1.767\text{x}\log(e)$$
$$\log y = 5.3172 - 0.7674x$$
$$\log N(M) = a - bM$$
$$b = 0.7674 \pm 0.0467$$

b. B-value Izu-Bonin Trench



$$y = (2 \times 10^6)e^{-1.974x}$$
$$log\, y = log(2 \times 10^6) + log(e^{-1.974x})$$
$$log\, y = log(2 \times 10^6) - 1.974x log(e)$$
$$log\, y = 6.301 - 0.8573x$$
$$log\, N(M) = a - bM$$
$$b = 0.8573 \pm 0.0489$$

c. B-value Japan Trench



$$y = (6 \times 10^6)e^{-1.87x}$$

$$\log y = \log(6 \times 10^6) + \log(e^{-1.87x})$$

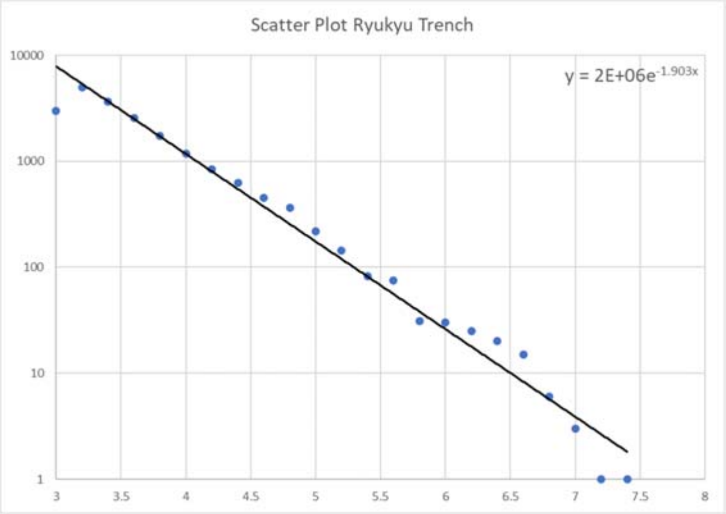
$$\log y = \log(6 \times 10^6) - 1.87x\log(e)$$

$$\log y = 6.77 - 0.8121x$$

$$\log N(M) = a - bM$$

$$b = 0.8121 \pm 0.0210$$

d. B-value Ryukyu Trench



$$y = (2 \times 10^6)e^{-1.903}$$

$$log\ y = log(2 \times 10^6) + log(e^{-1.903})$$

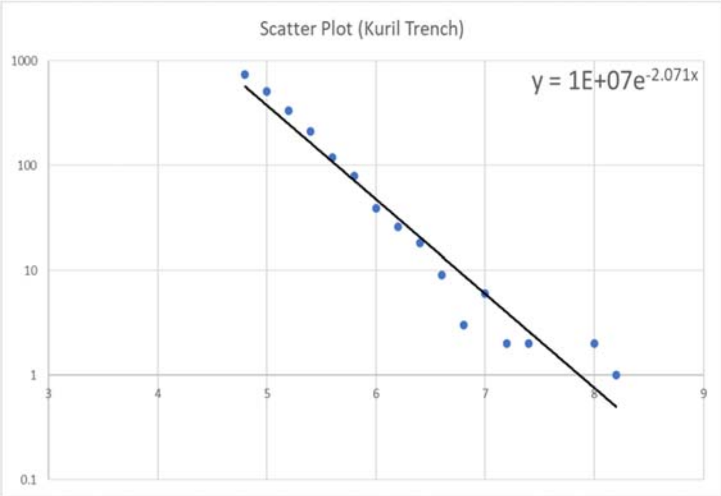
$$log\ y = log(2 \times 10^6) - 1.903 log(e)$$

$$log\ y = 6.301 - 0.8265x$$

$$log\ N(M) = a - bM$$

$$b = 0.8265 \pm 0.0277$$

e. B-value Kuril Trench



$$y = (1 \times 10^7)e^{-2.071}$$

$$log\, y = log(1 \times 10^7) + log(e^{-2.071})$$

$$log\, y = log(1 \times 10^7) - 2.071 log(e)$$

$$log\, y = 7 - 0.899x$$

$$log\, N(M) = a - bM$$

$$b = 0.8990 \pm 0.0563$$