How Many Explosive Eruptions are Missing from the Geologic Record?
Analysis of the Quaternary Record of Large Magnitude Explosive Eruptions in Japan.

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1. Introduction

Explosive eruptions of the Japanese islands, which are included in The Large Magnitude Explosive Eruptions database of Volcano Global Risk Identification and Analysis (VOGRIPA) project, are analyzed to understand the preservation potential of eruptions with time. The database contains information about the age of eruptions, pyroclastic ejecta volume, VEI (Volcanic Explosivity Index), magnitude and data source of volcanic records. The database attempts to include all known explosive eruptions to 1.8 Ma and VEI magnitude 4 or greater. We use this database to explore the preservation of products of explosive eruptions and patterns of volcanic activity in Japan.

2. Data sources

The Large Magnitude Explosive Eruptions database of VOGRIPA has been systematically compiled from primary and secondary sources. Major data sources of explosive events in Japan are as follows:

1) The one million year tephra database
(http://gunma.zamurai.jp/database/index.php?kind=1m&mode=)

2) 2000 year eruption database
(http://gunma.zamurai.jp/database/index.php?kind=2k&mode=)
Data source 1) and 2) are organized by Prof. Hayakawa at the Gunma University, Japan.

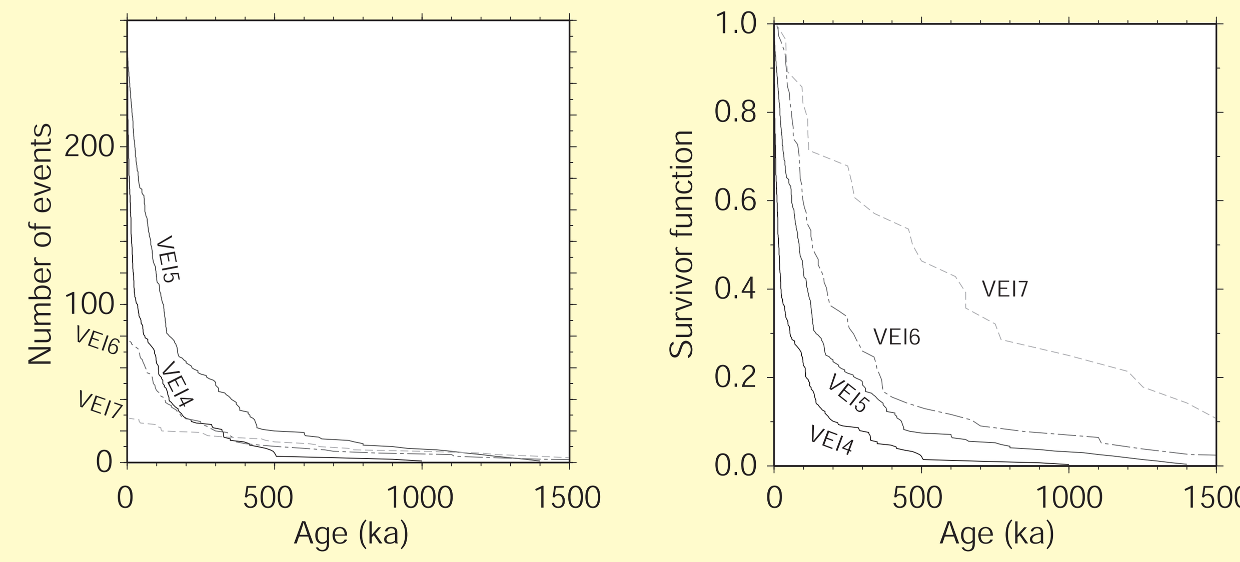
3) Active volcano database of Geological survey of Japan
(http://riodb02.ibase.aist.go.jp/db099/index-e.html)

4) Quaternary volcano catalog of the Volcanological Society of Japan
(http://www.geo.chs.nihon-u.ac.jp/tchiba/volcano/index.htm)

5) Machida H, Arai F (1993) Atlas of tephra in and around Japan. Univ Tokyo Press, Tokyo

3. Compiled data

The database contains 696 explosive eruptions. Half of these eruptions occurred within the last 65 ka; 77% of the total eruptions occurred since 200 ka; the oldest eruption in the database is 2.25 Ma. In addition, percentages by eruption magnitude are: VEI 4 (40%), VEI 5 (42%), VEI 6 (13%) and VEI 7 (5%).



Smaller eruptions are more rarely preserved than larger ones. Erosion of units must be the reason of this trend.

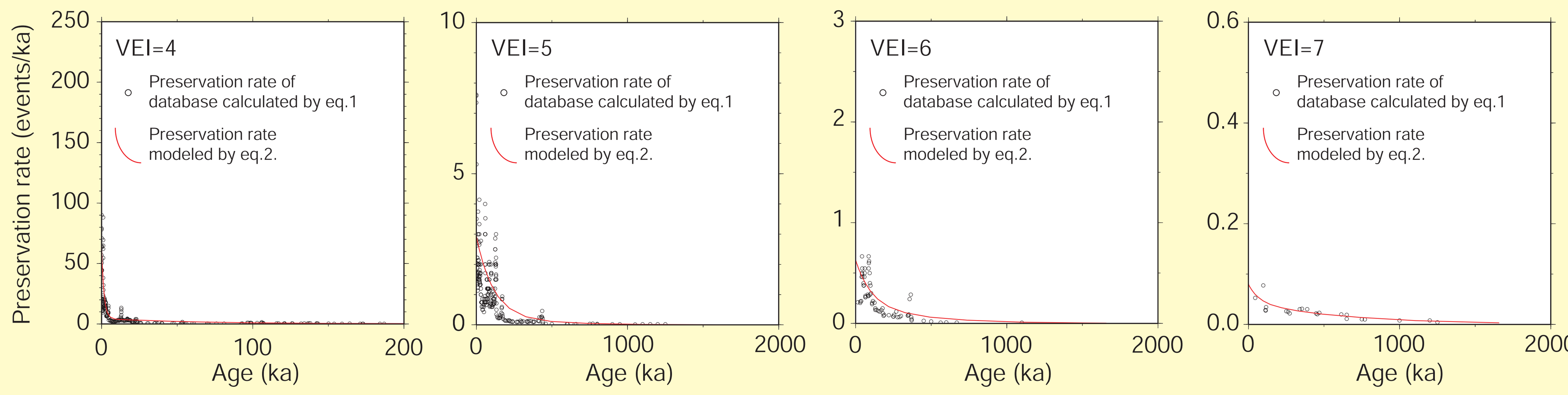
4. Estimation of the number of missing events

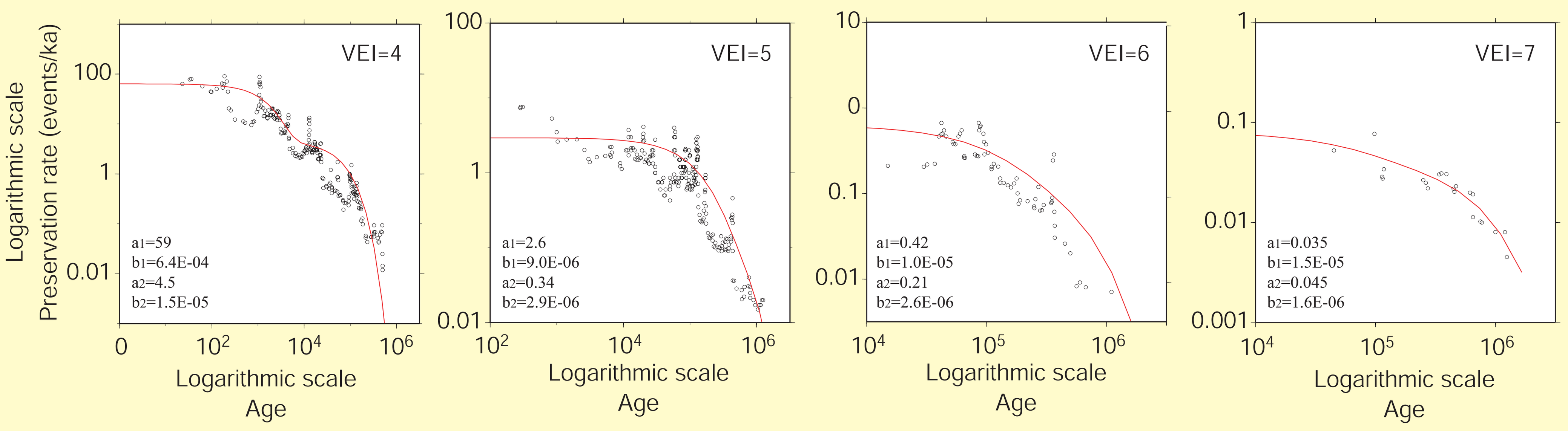
4.1. Preservation rate of event

Preservation rate of event is calculated with moving average:

$$r_m = 2n/(d_{m+n}-d_{m-n}) \quad ...eq.1$$

where rm and dm are the preservation rate and age of the mth youngest event respectively. 2n is the number of events to calculate the preservation rate of mth event. In this example n=3.



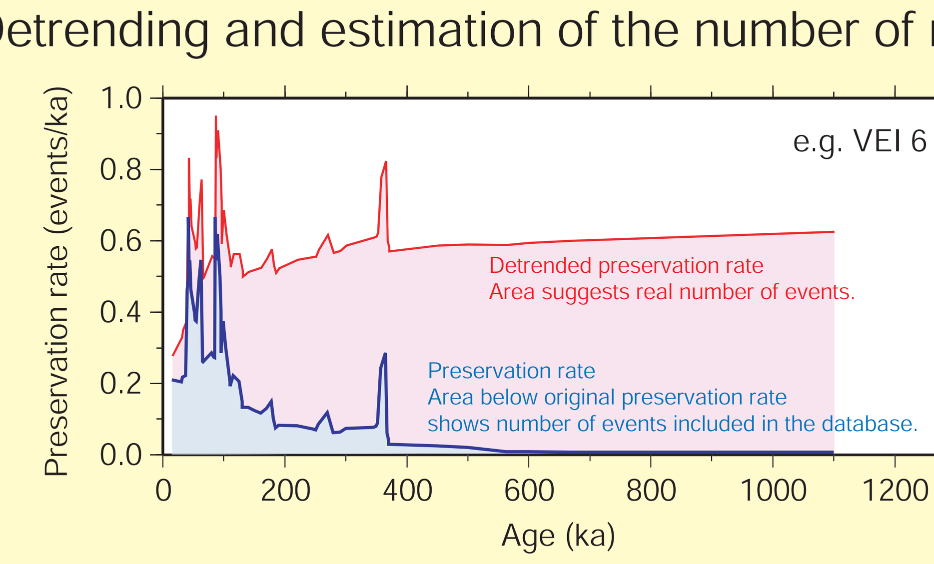


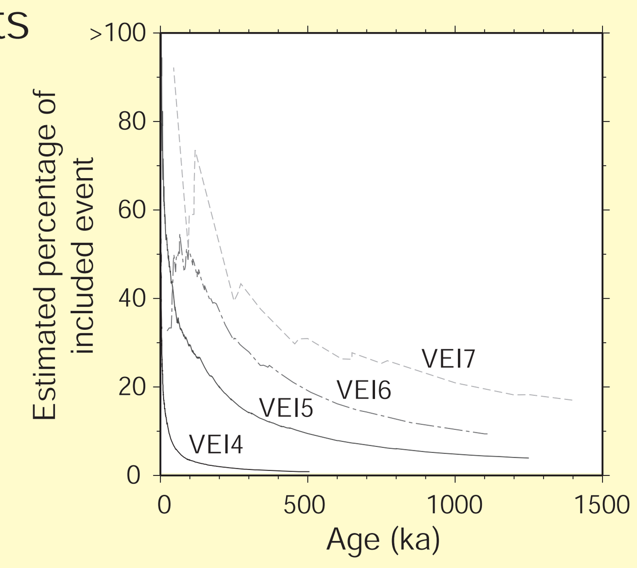
The change of identified eruptions in the geologic record with time shows two major trends. The likelihood of an eruption preserved in the last 10 to 100 ka follows an exponential trend, suggesting that many young deposits are rapidly eroded and are missing from the geologic record. Older deposits exhibit a gentler trend, indicating that once the deposit is initially preserved it is more likely to be identified in the geologic record than suggested by simple exponential decay. Therefore double exponential decay function is applied to model the preservation rate:

$$R_t = R_1 \exp(-\lambda_1 t) + R_2 \exp(-\lambda_2 t) \quad ...eq.2$$

where Rt is the preservation rate of events that occurred t years ago. R1 is the initial value of preservation rate of units which will quickly disappear with time due to erosion. R2 is the initial value of preservation rate of units which will be preserved for a long time but finally become unidentifiable in the long period. λ1 and λ2 are decay constants of the exponential decay function.

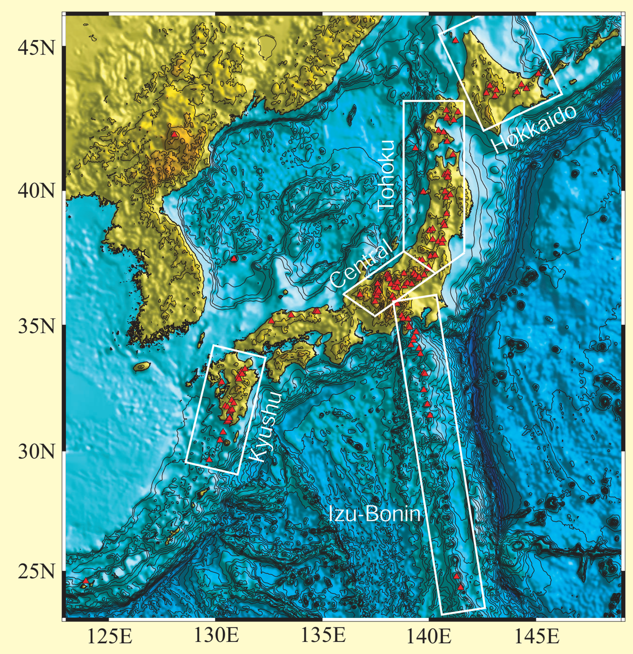
4.2. Detrending and estimation of the number of missing events



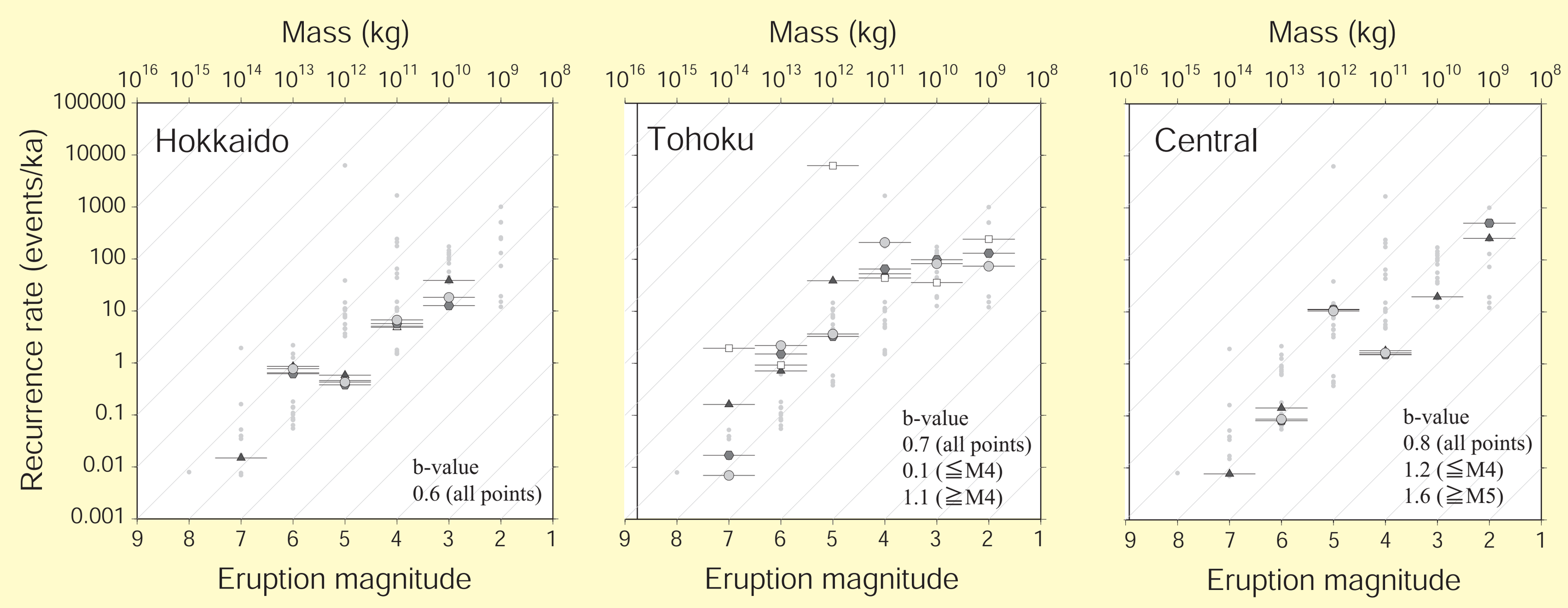


The observed frequencies of explosive eruptions by VEI (preservation rate) are modeled by functions and detrended. The results suggest 97 % of VEI 4 events are missing from the record after 100 ka, whereas 40 % for VEI 5 to 7 are missing after this time period. These results indicate that eruption probabilities based on long term recurrence rate must account for the potential for even large eruptions to be missing from, or unidentified in, the geologic record.

5. A "b-value" for eruption rates by tectonic region in Japan



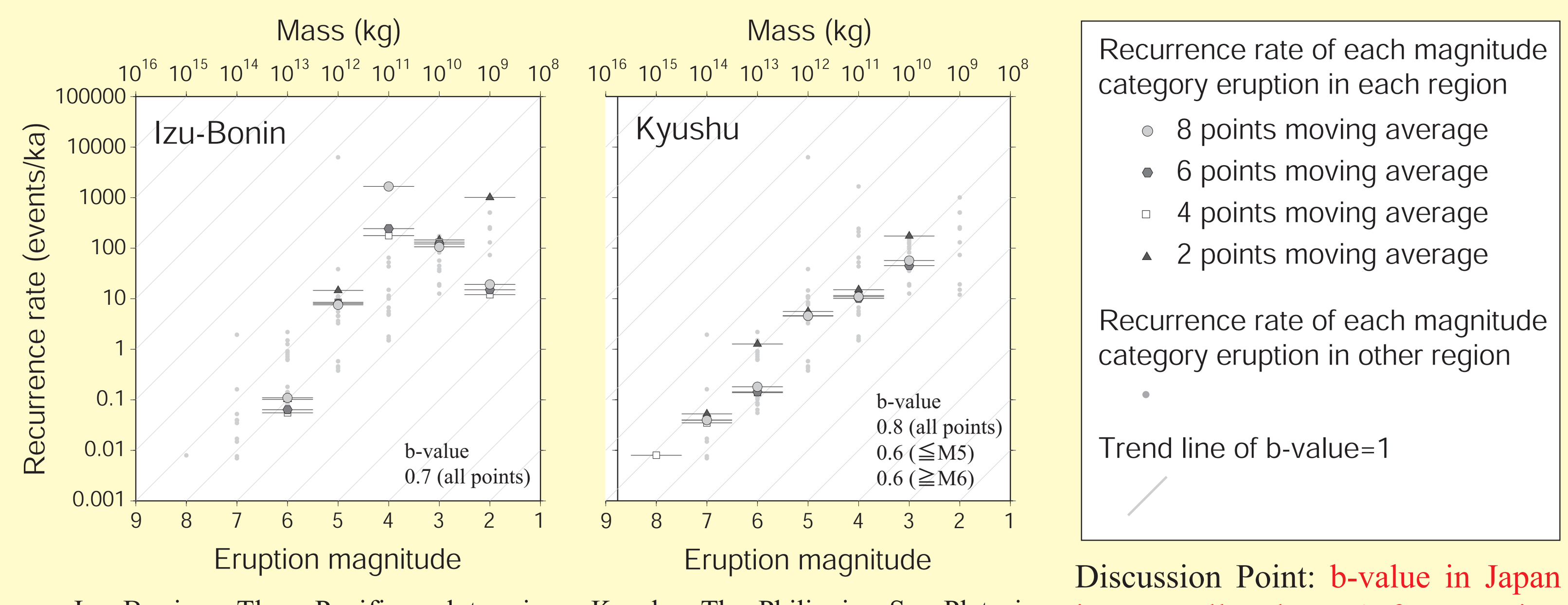
The database is used to estimate recurrence rate as the sum of preservation rates R_1 and R_2 in eq.2, which gives the estimated recurrence rate at t=0 for each eruption magnitude. As in seismology, the b-value reflects the frequency of eruptions as a function of magnitude. Now, lava volume is included and magnitude is used to calculate b-value for each tectonic region in Japan instead of VEI (which depends on tephra volume only). The b-value is useful because it does not depend on total number of events. Does the eruption magnitude b-value change with different tectonic settings in Japan?



Hokkaido: The Pacific plate is subducting beneath the North American plate. A single b-value characterizes the trend and is a little bit less than 1.

Tohoku: The Pacific plate is subducting beneath the North American plate. Smaller eruptions are much less frequent than expected for a b-value = 1. One explanation is that small volume magma batches solidify as intrusions more frequently than expected (compare with Hokkaido and Kyushu), possibly due to thicker or cooler crust.

Central Japan: The Philippine Sea Plate and the Pacific plate exist below the Eurasia plate and the North American plate in this complex zone. The b-value is approximately 1. Higher recurrence rate of M=5 eruption and less recurrence rate of smaller eruption than expected value may suggest magma storage below the surface.



Izu-Bonin: The Pacific plate is subducting below the Philippine Sea Plate. The b-value is very poorly resolved, likely because many eruptions in this marine arc are not reported.

Kyushu: The Philippine Sea Plate is subducting below the Eurasia plate. The b-value =1, very similar to Hokkaido.

Discussion Point: b-value in Japan is generally about 1 for eruption magnitude. However, it appears that the crust has a stronger influence on the magnitude-frequency of eruptions in Tohoku than in Kyushu or Hokkaido, causing a change in b-value.

6. Acknowledgments

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