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Temporal and Spatial Variations of Seismicity during the 1998 Hida Mountain Earthquake Swarms, Central Honshu, Japan

—— Preliminary Results ——

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Synopsis

We analyze the spatio-temporal distribution of b-value in the frequency-magnitude relation of earthquakes, for the 1998-1999 Hida Mountain earthquake swarms. We found a b-value that varies from 0.8 to 1.5-1.7 when depth is increasing from 4 to 6km. The high b-value is located in a crustal region that is characterized, according to some previous studies, by low-velocity and low-density. The results suggest that the b-value can be a useful tool for mapping such "anomalous" areas, possibly associated with magma movements. Our study confirms other similar investigations in volcanic areas.

Keywords: volcanic region; seismicity; b-value; magma; Yake-dake volcano

1. Introduction

The seismic activity that occurs in volcanic regions can give valuable information on some processes associated with magma movement. One of the most important parameters to characterize seismicity is the b-value, defined as the slope of the frequency-magnitude distribution of earthquakes. A high b-value shows a relative abundance of smaller events comparing with larger ones. Extensive laboratory and field studies suggest that an increased material heterogeneity or a high thermal gradient can cause an increase in b-value from an average of about one. In several papers (Wyss et al., 1997, Wiemer et al., 2001, for example), the authors map spatially the b-value in several volcanic regions in United States and Japan. They found a high value of b, probably associated with the cracking produced by magma intrusion or the presence of a magma chamber. These studies suggest that the b-value may be a useful tool for studying and tracing the magma-related processes and also for volcanic hazard assessment.

2. Data and method of analysis

Large earthquake swarms in the Hida Mountains started in August 1998 and continued for about one and a half years. The Kamitakara Observatory, Kyoto University, has located more than 9200 events in this time period (Wada et al., 1999). We analyze the seismic activity from August 1998–end of 1999, especially the temporal and spatial variations in the frequency-magnitude distribution of earthquakes. Figure 1 shows the epicentral map of the events. The focal depth is shallower than 20 km. Only the events from Aug.25–

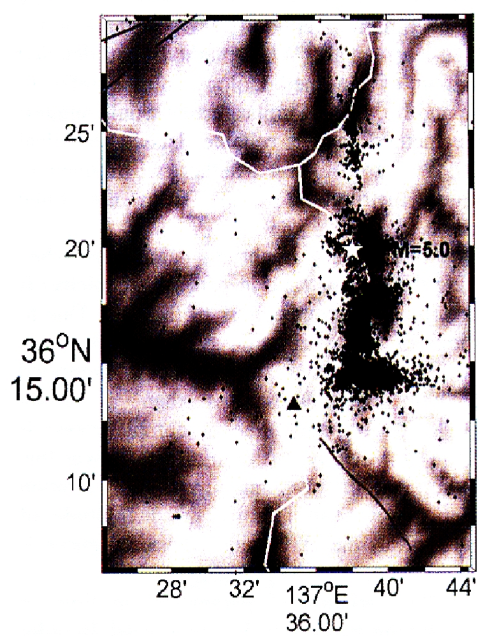

Fig. 1 Epicenter map of the 1998-1999 Hida Mt. earthquake swarms.

Nov.10 are selected when analyzing the depth variation of b-value, because four more stations were installed in this time interval, for intense observation, in and around the swarm-activity area, and the b-value does not vary significantly in time during this period. Most of our computations are done using the analysis tools of ZMAP software (Wiemer and Zuniga, 1994, Wiemer et al., 1995).

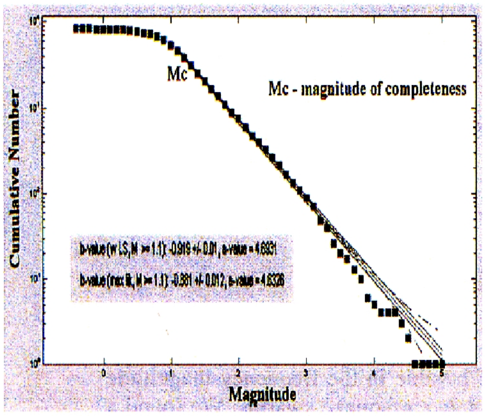

Fig.2 Magnitude of completeness, Mc, and b-value for all data. The b-value is found to be about 1.0, using both ML and WLS methods.

The frequency-magnitude distribution (Gutenberg and Richter, 1944) describes the relationship between the frequency of occurrence and magnitude of earthquakes:

$$\log_{10}N = a - bM, \quad (1)$$

where N is the cumulative number of events having magnitude larger than and equal to M, and a and b are constants. The b-values are determined using both a maximum likelihood (ML) method and a weighted-least-square (WLS) method; for a detailed explanation of the methodology, please refer to Enescu and Ito, 2002. Similar results would suggest that the methodology is reliable. Utsu's statistical test (1992) is used to test whether two frequency-magnitude distributions come from the same population.

One of the very important parameters when analyzing the b-value (and in general seismicity) is the magnitude of completeness of the data. Due to limitations of the observation system or the noise level in a certain area, the number of reported events with magnitudes less than a certain magnitude (called magnitude of completeness) is less than in reality. Assuming a power-low distribution for the frequency-magnitude relation (equation 1), we can identify the magnitude of completeness as the magnitude where the curve is bending in a $\log_{10}N$ vs. M plot (Fig. 2).

For the variation of parameters in time or depth, a moving-window technique is used. In order to analyze the distribution of b-value in space, we used a dense grid of points and compute the b-value for each node of the grid, taking into account the magnitude of completeness of the data (see, for example, Wiemer and Wyss, 1997).

3. Results and discussion

The magnitude of completeness (Mc) for all data is found to be around 1 (Fig. 2). However, when representing the variation of Mc in time, values bigger than one are found (Fig. 3). This result is taken into account when computing the time variation of b-value, shown in Fig. 4 (Mmin = 1.5; number of events in a moving window = 200). The b-value increases steeply from an average of 0.8, reaches a maximum of about 1.2, and then decreases gradually in time to about 0.8-0.9. The relative increase in b-value occurs during the

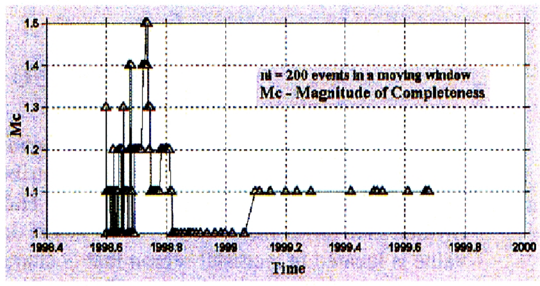

Fig. 3 Mc variation with time.

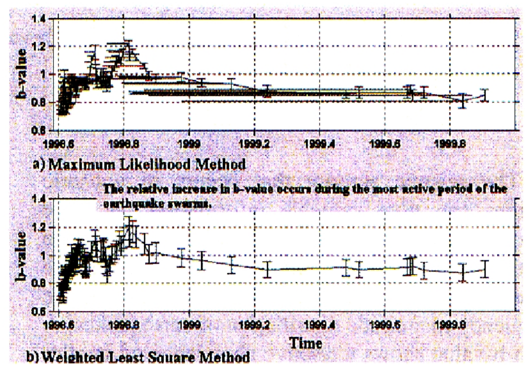

Fig. 4 Variation of b-value in time determined by using: a) ML and b) WLS methods.

most active period of the earthquake swarms. Both ML (a) and WLS (b) methods show a similar pattern of b-value variation.

An interesting feature is observed when representing the depth variation of the frequency-magnitude distribution (Fig. 5): until about 4.5 km depth b-value oscillates around an average of about 0.8, then b-value starts increasing, reaching a maximum of about 1.5-1.7 at around 5.5 km, below which gradually decreases with depth.

In order to have more information on the variation of the frequency-magnitude distribution in space, we compute a cross-sectional map of b-value, using a gridding technique. Again, some anomalous, high b-values can be observed (Fig. 6). They are localized in the south part of Hida Mountain, below 4km depth. Figure 7 shows two frequency-magnitude distributions observed in regions with high b-values and low b-values respectively. We have computed the probability P that the two distributions come from the same population (Utsu, 1992). The very small value of P (3.4×10^{-15}) is a proof that the differences in b-value found in the cross-sectional view are highly significant.

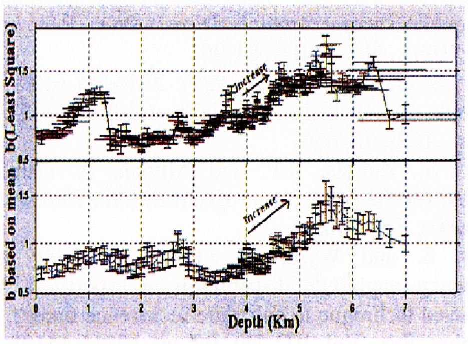

Fig. 5 Variation of b-value with depth by using WLS and ML methods. Mmin = 1; time-window = 100 events and max. depth = 15km.

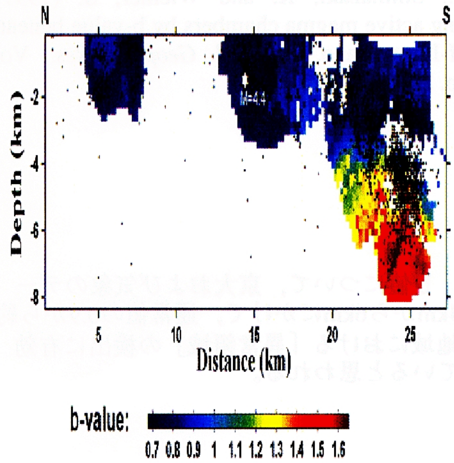

Fig. 6 Cross-sectional view of b-value in N-S direction. Grid-spacing is 0.2km. A b-value at each node was determined by using the ML method.

The anomalous b-values occur in a crustal volume characterized by relatively small size earthquakes, as can be seen in Fig. 8: most of the shocks with M ≥ 3 are located between 0-4 km depth.

The high b-value anomaly is observed in the same region, at about the same depths, when using JMA data, even though there are some differences between the hypocentral locations in the two catalogues. Therefore, more accurate hypocenter locations are desirable and we are planning this for our future study.

Possible explanations for these high b-values include increased heterogeneity, temperature and stress conditions. Such anomalies were reported in several volcanic areas, sometimes occurring during earthquake swarms. It is interesting to note in this respect that several studies (Katsumata et al., 1995, for example) showed that the crust at 5-15 km depth beneath Hida Mountain Range is characterized by low Q, low velocity and low density. Thus, an increase in cracking or heterogeneity of the material and the presence of a partial melt in the porous region (increased temperature) may be valuable explanations for the observed high b-values.

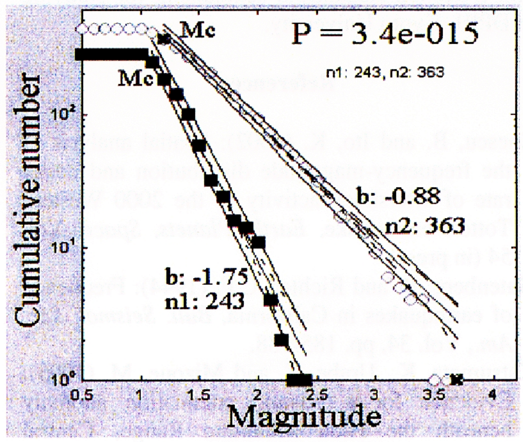

Fig. 7 Comparison between b-values of two representative samples in Fig. 6. The b-value and number of events are given at each distribution. Mc is the magnitude of completeness.

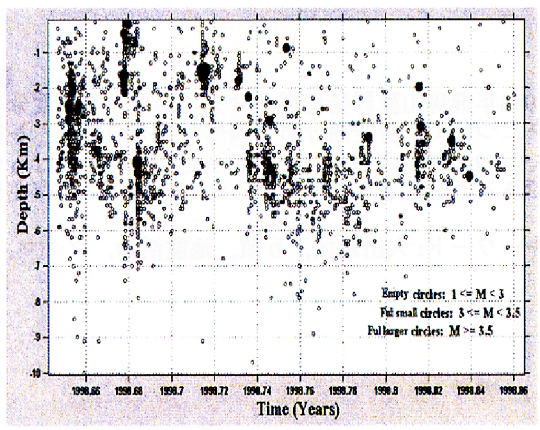

Fig. 8 Time-depth distribution of seismicity. Large, solid circles show events of M ≥ 3.5, small, solid circles, 3.0 ≤ M < 3.5 and open circles, M < 3.0.

4. Conclusions

1. The frequency-magnitude distribution shows a statistically significant variability in time and space during the 1998-1999 Hida Mountain Earthquake swarms.
2. During the most active period of the earthquake swarms, a relative increase in b-value can be noticed.
3. Some anomalous, high b-values can be observed in the south part of Hida Mountain, below 4km depth.
4. The high values of b below 4km depth seem to agree with reported low Q, low velocity and low density in the crust, between 5-15 km depth.

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要　旨

1998年飛騨山脈群発地震のマグニチュード頻度分布の係数，b値について，京大および気象のデータについて，時空間分布を調べた。その結果，b値が深さ4kmから6kmにかけて，通常値の0.9から約1.5−1.7に増加することがわかった。このことはb値が火山地域における「異常領域」の検出に有効であることを示している。これらはマグマの存在に関連していると思われる。

キーワード: 火山地域，b値，地震活動，マグマ，焼岳