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Preliminary Statistical Analysis of the Seismicities in the Antarctic Peripheral

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ABSTRACT. Statistical analysis of earthquake data reported to worldwide catalog from 1990 to 1998 provides characteristics of earthquake occurrence patterns in the tectonic groups around the Antarctica. Annual occurrence of the earthquake in the Antarctic peripheral ranging from 90°S to 50°S has increased since 1990. Strain energy, accumulated since 1990, had been released by a big stress drop in 1993 at the northern Antarctic Peninsula. Strain energy has been accumulating again since 1993 until now. Small scale earthquakes are frequent in the tectonic groups including the Pacific-Antarctic Ridge and the Southeast Indian Ridge, where relatively large portion of the strain energy has been released through the small scale earthquakes. On the other hand, relatively small portion of the strain energy is released by the small scale earthquakes in the Atlantic-Indian Ridge and Macquarie Ridge. Generally the frequency of the annual occurrence in the vicinity of the northern Antarctic Peninsula is increasing since 1990, although maximum stress drop took place in 1993. Earthquake occurrence pattern in the South Sandwich Trench and Scotia Ridge is similar to that of the Antarctic average. The earthquake occurrence pattern in the Shackleton Fracture Zone, however, shows different characteristics comparing other tectonic units in the Antarctic peripheral. The strain energy has been mostly released through few large scale earthquakes in the Shackleton Fracture Zone.

Key Words: Antarctic peripheral, earthquake, statistical analysis, stress, strain

Introduction

Statistical analysis of earthquake in each tectonic group around the Antarctica is an indicative study of tectonic interactions among tectonic groups. Most earthquakes took place along the tectonic boundaries such as divergent, convergent, and transform boundaries. Divergent boundaries around the Antarctic area ranging from 90°S to 50°S include the Scotia Ridge (SR), the America-Antarctic Ridge (AAR), the Atlantic-Indian Ridge (AIR), the Southeast Indian Ridge (SIR), the Macquarie Ridge (MR), and the Pacific-Antarctic Ridge (PAR) (Fig. 1). Major convergent boundaries include the South Sandwich Trench (SSaT) and the South Shetland Trench (SST). The ridges in the Antarctic peripheral are extending to further north (<50°S) except the SR, AAR, and PAR. Seismicity in a group could represent unique tectonic characteristics and probably interaction among groups. However, no constraint has been placed on those plate interactions in this preliminary study. Main land of the Antarctica is too far away from those tectonic groups and therefore is generally free from those tectonic interactions (Fig. 1). However, the northern Antarctic Peninsula could show complex tectonic structures such as the SR, SFZ, and the Bransfield Basin (BB) rifting system are located nearby. Thus, preliminary statistical analysis

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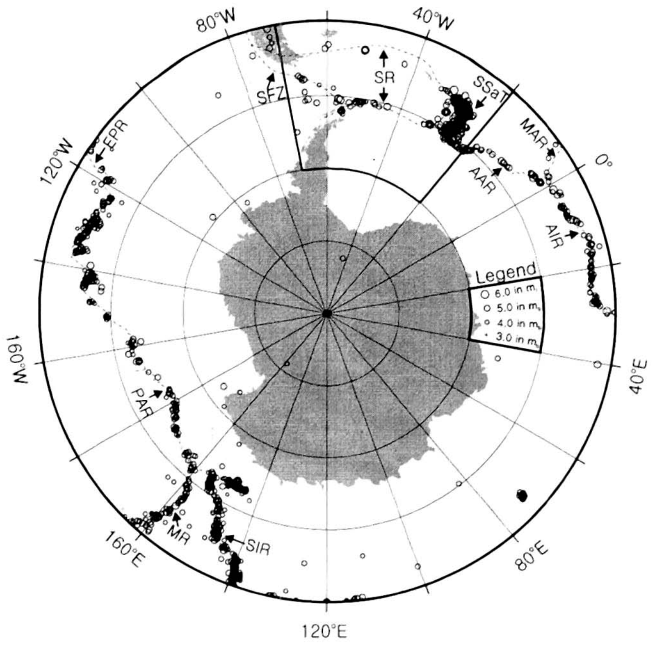

Fig. 1. Earthquake occurrence around the Antarctica reported to NEIC catalog during the period from 1990 to 1998. Solid box in the northern Antarctic Peninsula is magnified and plotted in Fig. 2. Tectonic groups include the Scotia Ridge (SR), the Shackleton Fracture Zone (SFZ), the South Sandwich Trench (SSaT), the Mid-Atlantic Ridge (MAR), the America-Antarctic Ridge (AAR), the Atlantic-Indian Ridge (AIR), the Southeast Indian Ridge (SIR), the Macquarie Ridge (MR), the East Pacific Rise (EPR), and the Pacific-Antarctic Ridge (PAR).

of earthquakes in each tectonic group is important for discriminating its tectonic characteristics.

Most of the previous earthquake studies in the Antarctic area have been confined only to the northern part of Antarctic Peninsula including the Scotia Sea (Pelayo and Wien, 1989; Privitera *et al.*, 1994) and Bransfield area (Vila *et al.*, 1992; Lee *et al.*, 1998; Jin *et al.*, 1998), although Kaminuma (1995) studied seismicity around the Antarctic Peninsula. Vila *et al.* (1992) have reported active seismicity on Deception Island associated with the volcanic activity. Pelayo and Wiens (1989) have studied relative plate motion in the Scotia Sea including tectonic boundaries such as SR, BB, and SFZ. Lee *et al.* (1998) have suggested active seismicity in the North Bransfield Basin and the South Shetland Platform, although the driving force of those seismicity is still in debate.

In this paper, we use a NEIC catalog (NEIC, 1999) for earthquakes which took place in the Antarctic peripheral (90°S~50°S) during the period from 1990 to 1998. Local earthquakes, less than 4.0 in body wave magnitude, generally can not be easily reported to NEIC catalog because only few seismic stations can cover the earthquakes in those area. Earthquake information includes origin times, locations, focal depths, and magnitudes. The purpose of this paper is to provide earthquake occurrence patterns of the tectonic groups in the Antarctic peripheral especially in the northern Antarctic Peninsula. In each tectonic group, annual earthquake occurrence and accumulated frequency for each magnitude have been calculated. The "*b*" value for each tectonic zone has been estimated and compared to study the general earthquake occurrence pattern in a tectonic group. The result of this study will be used for future study to scrutinize the tectonic interaction among the tectonic groups especially the north Antarctic Peninsula. Future analysis of analog earthquake data recorded at King Sejong Station will provide information about the earthquake characteristics of the Bransfield basin system.

Approach

More than fourteen hundred earthquakes have been reported to NEIC catalog during the period from 1990 to 1998 near the Antarctic peripheral ranging from 90°S to 50°S. Most common measurement of earthquakes for statistical analysis is magnitude, although a variety of different magnitudes are currently used. To analyze seismic characteristics in a group, Gutenberg-Richter (1954) model has been generally used. The distribution of earthquake magnitude over a limited range of the magnitudes is known to satisfy

$$log_{10}^{N} = a - bM$$

where N is accumulated frequency of earthquakes in a tectonic group having magnitudes larger than M, and a and b are constants. In the above equation, b is clearly statistical constant in a least square sense that measures the proportions of small and large earthquakes in a tectonic group. Small scale earthquakes are relatively common when b is large, while small earthquakes are rare for small *b* value. The relationship between stress or stress drop and *b* value have been addressed by several authors (Scholz, 1968; Wyss, 1973; Hanks, 1979; Frohlich and Davis, 1993). Generally higher stress drop correspond to lower *b* values. However, the magnitude scales for estimating *b* values in this study (body wave magnitude) are different from that used by Gutenberg-Richter model. The magnitude scale for a catalog can not directly be compared to another catalog because those catalogs might use different magnitude scales. Therefore, direct comparison of b values is meaningless if we use several different earthquake catalogs. In this study, we use a single catalog from NEIC. Relative comparison of *b* values is, therefore, reasonable although this magnitude scale is different from that by Gutenberg-Richter model.

One simple way to determine *b* value is to measure the slope of the log-frequency versus magnitude, taking relatively narrow band for magnitude to estimate. Over this band the slope should be strait enough, and we should select a range where the magnitude scale measures earthquake size consistently. Aki (1965) proposed maximum likelihood method for measuring *b* value for a catalog in such sense that magnitudes exceed some minimum magnitude (M_{min}). Maximum likelihood method has been modified by many authors (Utsu, 1966; Page, 1968; Bender, 1983). In this study, however, we applied simple linear fitting of the slope of the log-frequency versus magnitude. We chose magnitude band where the curve is strait enough. At the same time, we also applied same minimum magnitude (4.5) for magnitude band to estimate b values for the different zones (tectonic groups) around the Antarctica because our primarily goal of this study is to find differential characteristics of the earthquake occurrence pattern among groups.

Major tectonic groups around the Antarctic peripherals include PAR, AIR, AAR, MR, SIR, SSaT, SR, and SFZ as shown in Fig. 1. Around the northern Antarctic Peninsula, we have divided a group into three sub-tectonic groups as *zone1*, *zone2*, and *zone3* as shown in Fig. 2. *Zone1* includes the South

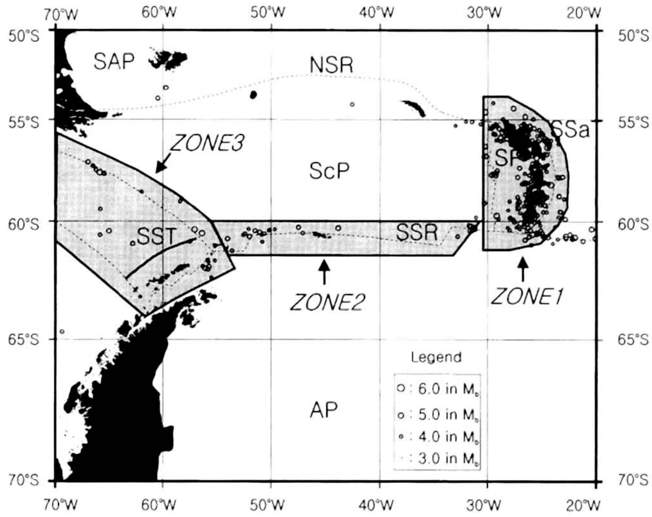

Fig. 2. Zoning of the major tectonic groups in the northern Antarctic peninsula. Major tectonic structures such as the South America Plate (SAP), Antarctic Plate (AP), Scotia Plate (ScP) , Sandwich Plate (SP) are included in this plot. SSR represents the South Scotia Ridge, while NSR the North Scotia Ridge. Earthquake locations are plotted as empty circle, whose diameter is proportional to the magnitude (m_b) as shown in the legend.

Sandwich Trench, *zone2* the South Scotia Ridge, and *zone3* SFZ, HFZ, and BB as shown in Fig. 2.

Result

Antarctic Peripheral

In the Antarctic area ranging from 90°S to 50°S, annual occurrence of earthquakes has been generally increasing since 1990 except 1994 as shown in Fig. 3-a. However, energy release pattern is not proportional to the annual occurrence (Fig. 3-b). Large stress drop was observed in 1993, when the annual occurrence was relatively small but maximum energy was released. Since 1993, annual occurrence of relatively small scale earthquakes has been increasing, where as annual energy release has been generally decreasing. This might suggest that the strain energy has been gradually accumulating since 1994 and relative large stress drop took place in 1998 (Fig. 3-b). In 1993, big stress drop was done by few large scale earthquakes in the SFZ, while stress drop was evenly done within certain magnitude band after 1993. This might suggest that the strain energy is still accumulating since 1993 around the Antarctic

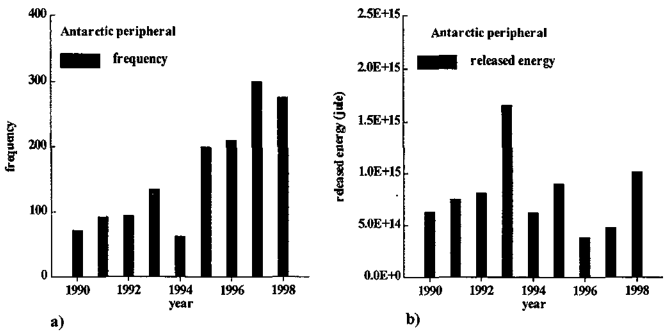

Fig.3. a) Annual occurrence and b) annual energy release of the earthquakes in the Antarctic peripheral.

Table 1. Estimated b values for tectonic groups around Antarctica

area	number of data	magnitude band	*b* value
Antarctic peripheral	1447	5.0~5.9 (4.5~6.1)	1.33 (1.22)
Pacific-Antarctic Ridge	222	5.0~5.7 (4.5~5.7)	1.76 (1.45)
Atlantic-Indian Ridge	81	4.9~5.5 (4.5~5.7)	1.04 (1.01)
America-Antarctic Ridge	23	5.1~5.4 (4.5~5.3)	2.00 (0.53)
Macquarie Ridge	57	4.5~5.5 (4.5~5.7)	1.11 (1.07)
Southeast Indian Ridge	157	5.1~5.7 (4.5~5.7)	1.96 (1.29)
BB, SFZ, and HFZ	28	4.0~6.0 (4.5~6.2)	0.54 (0.59)
Scotia Ridge	40	5.0~5.8 (4.5~6.0)	1.25 (1.10)
South Sandwich Trench	555	5.0~6.0 (4.5~6.1)	1.39 (1.30)

peripheral. Large stress drop, therefore, is expected in a very near future in the Antarctic peripheral.

The estimated *b* values using same minimum magnitude for the magnitude band listed in the parenthesis in Table 1 are sometimes much different from those derived using correct band of the magnitude listed in the outside of the parenthesis. The estimated *b* value as shown in Fig. 4-d, take an example, can be large when we take minimum magnitude of the band as 5.1 where the curve becomes strait. Only relative comparisons for *b* values have been made among tectonic groups because the absolute *b* value is meaningless. The overall *b* value

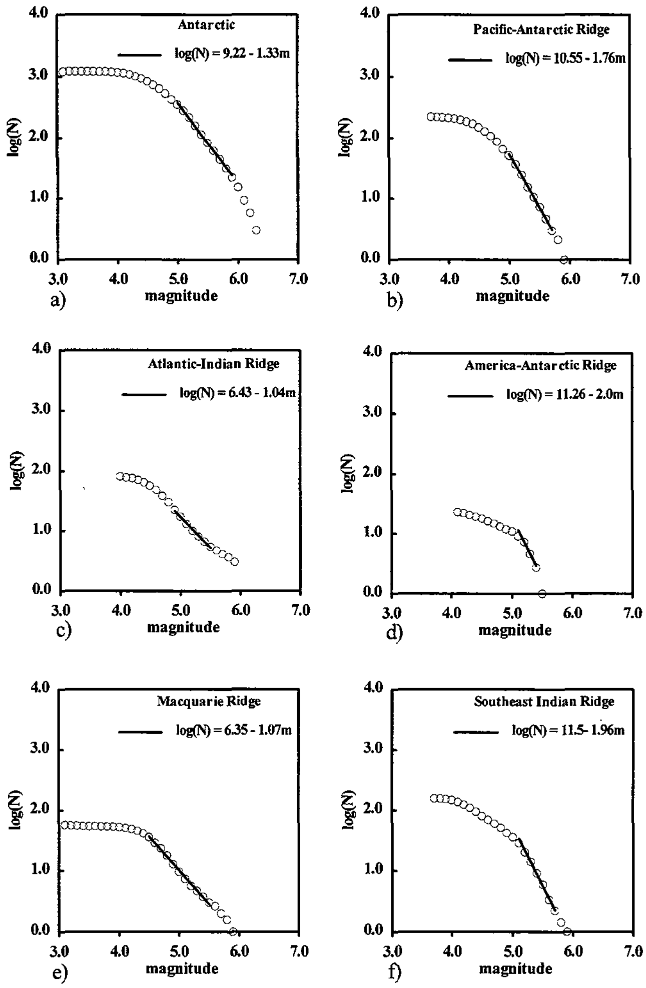

Fig. 4. Measured *b* values corresponding to a) Antarctic peripheral, b) PAR, c) AIR, d) AAR, e) MR, and f) SIR. Magnitude bands with strait line have been selected and used to estimate *b* values.

for Antarctic peripheral is about 1.33 using magnitude band ranging from 5.0 to 5.9. If we assume that *b* of 1.33 is the average value of the Antarctic peripheral, then tectonic groups such as PAR and SIR have greater *b* values (Figs. 4-b and 4-f). Major stress drop patterns in PAR and SIR, therefore, seem to occur through relatively small scale earthquakes less than 5.0 in magnitude. On the other hand, tectonic groups such as AIR and MR have smaller *b* values, which might be indicative of that strain energy is released through relatively large scale earthquakes.

It is true that the choice of magnitude band for estimating *b* value is subjective and different *b* values can be derived using different magnitude band and scale. The estimated *b* values, however, can pro-

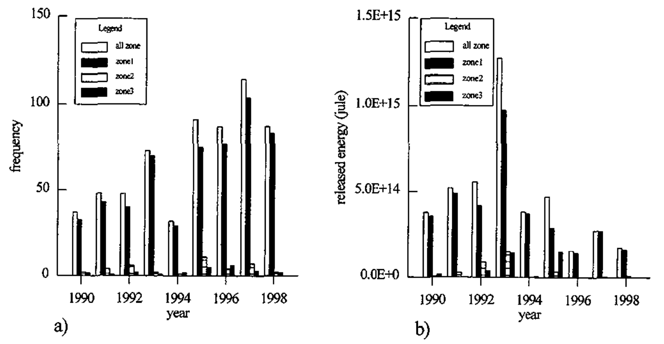

Fig. 5. a) Annual occurrence of the earthquakes and b) annual energy release of the earthquakes in the northern Antarctic Peninsula.

vide valuable information if we use these *b* values obtained by the same criteria for relative comparisons among tectonic groups in the Antarctic peripheral. The seismicity inside the main land of Antarctica is critically poor. Only two shallow earthquakes have been reported to NEIC catalog since 1990 (Fig. 1).

The northern Antarctic Peninsula

Three tectonic zones around the northern Antarctic Peninsula have been presented and analyzed in terms of earthquake occurrence patterns (Fig. 2). *Zone1* includes the South Sandwich Trench system and the Sandwich Plate (SP). *Zone2* includes the South Scotia Ridge and *zone3* consists of the BB, SFZ, and HFZ. Over 30 % of the earthquakes occurring in the Antarctic peripheral are concentrated in the *zone1* at the South Sandwich Trench system. Annual earthquake occurrence pattern in *zone1* is very similar to that of the Antarctic peripheral. The annual earthquake occurrence has been gradually increasing since 1990 (Fig.-5a). Main stress drop took place in 1993 (Fig. 5-b) and strain energy is accumulating since 1993. Similar pattern for earthquake occurrence in the *zone2* as well as *zone1* is observed. In the *zone3*, however, there were two large stress drop in 1993 and 1995 (Fig. 5-b). These stress drops in *zone3* mainly took place along the Shackleton Fracture Zone, which might show different earthquake occurrence pattern and tectonic characteristics comparing *zone1* and *zone2*. In the *zone3*, no earthquake has been reported to the NEIC catalog concerning the extension of the Central

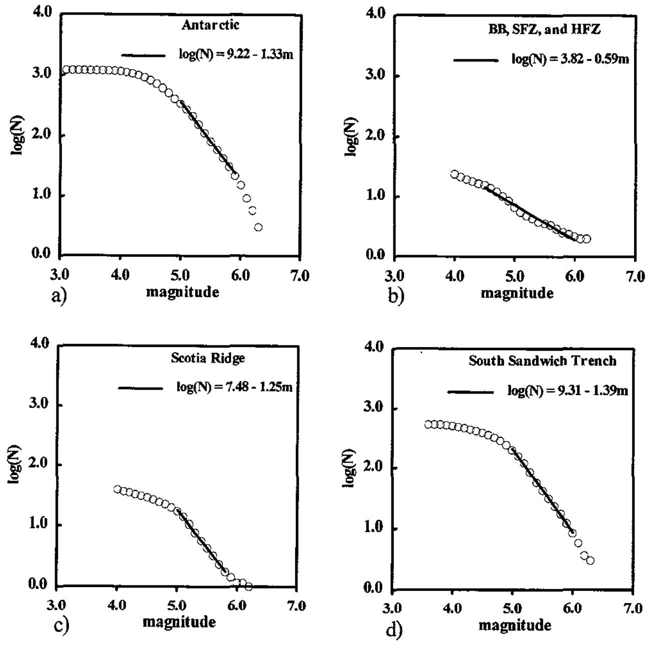

Fig. 6. Measured *b* values corresponding to a) Antarctic peripheral, b) BB,SFZ, and HFZ, c) SR, and d) SSaT

Bransfield Basin, although earthquakes related to the volcanic eruption in the North Bransfield Basin have been reported (Lee *et al.*, 1998). Also earthquakes associated with the volcanic eruption at Deception Island have been reported to the NEIC catalog. However, no earthquake has been reported along the South Shetland Trench in *zone3*.

The *b* values of *zone2* and *zone3* are very close to that of the average value of the Antarctic peripheral (Figs. 6-c and 6-d), while that of the *zone1* is much smaller than the Antarctic average (Fig. 6-b). This suggests that earthquake occurrence pattern in the SFZ is different from that of the ridge and trench systems in the Antarctic peripheral. Small earthquakes are rare, while large earthquakes are common in the SFZ.

Conclusion

In the Antarctic peripheral ranging from 90°S to 50°S, relatively small scale earthquakes are dominant in the tectonic groups such as the Pacific-Antarctic Ridge and the Southeast Indian Ridge comparing the Antarctic average. Through the Atlantic-Indian Ridge and Macquarie Ridge, relatively large scale earthquakes are common. The frequency of the earthquake occurrence is annually increasing since 1990 although a big stress drop was observed in 1993. Strain energy has been accumulating since 1993 in the Antarctic area. In the northern Antarctic Peninsula, earthquake occurrence pattern is similar to that of the Antarctic average in the area such as the Scotia Ridge and the South Sandwich Trench system. However, earthquake occurrence pattern shows different characteristics in the area including the SFZ, HFZ, and the Bransfield basin system. Strain energy in the SFZ seems to be mostly released by a few large earthquakes. Further investigation of earthquake occurrence pattern using local data recorded at King Sejong Station will give us more specifics about the earthquake occurrence pattern in the Bransfield basin system and the relationship among tectonic structures near by.

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