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Article

Local Seismic Activity around the Lützow-Holm Bay, East Antarctica

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Abstract : The seismic monitoring at Syowa Station (69°S, 39°E: SYO), located on the continental margin of the Eastern Dronning Maud Land, East Antarctica, began in 1959. Phase readings of the earthquakes have been reported since 1967 and have been annually published as part of the Data Report Series of the National Institute of Polar Research since 1968. An observation of a tripartite seismic network was carried out at SYO for a period of three years from 1987 to 1990. Epicenters of local earthquakes were determined for the first time by using the array network for the three-year period. Many different types of earthquakes, such as the mainshock-aftershock type, twin earthquake, earthquake swarms, etc., were detected during the period. After this, local events around SYO have been detected empirically from their waveforms recorded on seismograms. The seismic activity for the period of 1987-1990 was higher than that of the following decade. Earthquake epicenters, occurring during that period, were highly localized along the coast and in the central part of the Lützow-Holm Bay (LHB). Nine local earthquakes, recorded during the period of 1990-1996, showed many different types of events. The seismicity for the period of 1990-1996 was very low and the magnitudes ranged from 0.1 to 1.4. The locations of some events were determined by using the single station method for SYO, i.e., using the particle motions of the initial phase and S-P time. Two local events were detected in 1998 and one event in 2001. It would be estimated that the stress concentration was related to the glacial rebound around the LHB. Afterwards, we will be able to eventually examine the relationship between the seismicity around Antarctica and deglacial phenomena such as crustal uplift, and sea level change within the earth environmental system.

Key words : seismicity, local earthquakes, Syowa Station, intermittent activity, epicenter location

1. Introduction

In 1977, only two earthquake seismologists attended the 3rd international symposium on Antarctic Earth Science (ISAES), held in Madison, Wisconsin, U.S.A. They presented two papers concerning earthquakes. Most geoscientists believe that there are no earthquake activities in the Antarctic except for volcanic areas (Gutenberg and Richter 1954). More than ten seismologists attended the 9th ISAES held in Potsdam, Germany in September 2003. About 20 papers on seismic activities related to Antarctica, earthquake mechanism, etc. were presented at the symposium. It became common knowledge that there are some seismic activities in the Antarctic even though the activities are very low compared with other seismic areas.

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One basic element of research on the local seismicity in the Antarctic has been conducted around Syowa Station since the 1970s. The Japanese Antarctic Syowa Station (69°S, 39°E, SYO) was established for the International Geophysical Year (IGY) in January 1957. The seismological observation at SYO started using short period seismographs (HES) with a vertical component in 1957, and two horizontal component seismographs were added in 1961. Syowa Station was reopened in 1966 after a four-year hiatus. Seismological observation at SYO has been enhanced by three-component long and short period seismographs. Phase readings of the teleseismic events have been reported to the United States Costal Geological Survey (USCGS) for determine earthquake locations using a global seismic network (Kaminuma 1969, 1976).

In 1990, a three-component digital broadband seismograph (STS-1V, -1H) was installed at SYO (Nagasaka *et al.*

1992) as one of the permanent stations of the Federation of Digital Seismographic Networks (FDSN). Obtained digital waveform data has been published on the website of the National Institute of Polar Research (NIPR) and is also available from the PACIFIC21 data center at the Earthquake Research Institute (ERI), of the University of Tokyo. The waveform data was subsequently sent to the Incorporated Research Institutions for Seismology (IRIS) / Data Management Center (DMC) for public use of global researchers through the Internet.

In these three decades, in accordance with the above historical events, phase reading data of teleseismic events and detected earthquake lists at SYO were sent to the National Earthquake Information Center (NEIC) of the United States Geological Survey (USGS), together with the International Seismological Center (ISC) every year. The above two data sets have also been annually published from NIPR, as one of the 'Data Report Series (Seismology)'. The Data Reports represent scientific activities of the Japanese Antarctic Research Expedition (JARE) (e.g., Kanao 1999).

Although the Antarctic region is known as an aseismic region, some relatively significant earthquakes have occurred in the Antarctic continent and the surrounding oceans. Earthquakes with a magnitude greater than 4.0 and some local events with a magnitude less than 3.0 have been detected in the first stage of Antarctic research (Kaminuma and Ishida 1971; Adams 1969, 1972, 1982; Adams *et al.* 1985; Kaminuma 1976, 1990). Because the seismic stations in the Antarctic have been operated as part of the global seismic network, detailed studies of local events have been made in recent years (e.g., Kaminuma 2000; Bannister and

Table 1. List of local earthquakes detected at SYO from 1990.

Date	Phase	Arrival time	P-S time	Propagating angle From North to East	Magnitude
1990 May 29	iP	07h36m33.5s	14,4 s		
	eS	07h36m47.9s			
1991 Jan. 12	iP	01h51m12,4s	15.2 s		
	eS	01h51m27.6s			
1991 May 29	iP	01h17m30.8s	9,9 s		
	iS	01h17m40.7s			
1992 Jan. 11	iP	12h49m07.1s	3.7 s		
	iS	12h49m10.8s			
1992 Sep. 21	iP	16h14m51.8s	7.2 s		
	iS	16h14m59.0s			
1993 Dec. 15	iP	04h13m16.5s	12.3 s	303°	0.6
	iS	04h13m28.8s			
1994 May 03	iP	10h10m13.3s	16.2 s	60°	1.4
	iS	10h10m29.5s			
1995 Sep. 28	eP	08h06m04.0s	13.0 s	309°	−0.4
	eS	08h06m17.0s			
1996 Aug. 03	iP	14h32m24.2s	13.2 s	52°	1.1
	iS	14h32m37.4s			
1997 Sep. 18	iP	03h11m29.0s	4.4 s	45°	
	iS	03h11m33.4s			
1998 Sep. 16	eP	10h32m14.5s	13.5 s	312°	
	iS	10h32m28.0s			
1998 Nov. 18	eP	04h36m23.5s	7.2 s	304°	
	eS	04h36m30.7s			
2001 Feb. 21	iP	04h35m13.0s	10.8 s	50°	
	iS	04h35m 23.8s			

Kennett 2002; Reading 2002).

A temporary seismic array with a tripartite network was established around SYO in 1987 and the observations continued until 1989 (Akamatsu *et al.* 1988, 1989; Kaminuma and Akamatsu 1992). The local seismic activity around SYO was at first analyzed using the seismic data from the local network. Micro and/or ultra-micro earthquake activities were recognized during the three-year period of 1987-1989. In this paper, we summarize the characteristics of time series for the occurrence of the local earthquakes around the Lützow-Holm Bay area over the last three decades.

Particularly, local seismicity in recent observation periods since 1987 was described in detail.

2. Local earthquakes

Several kinds of seismic events except tectonic earthquakes have been recorded on seismograms at SYO. These are, sea icequakes, seismic tremors with a duration of some ten seconds caused by ice calving at the edge of the continental ice sheet, etc. Local earthquakes on the seismograms at SYO were detected empirically by their waveform patterns. Based on the data from the tripartite array in 1987-1989, local events were characterized by a clear onset of P and S phases and S-P times of less than 30 s for the most part. The epicenters of those events were found to be located in Lützow-Holm Bay and along the coast. Since 1990, local events have mainly been detected by the three-component short period seismographs (a natural period of 1 Hz; HES seismograph) with a maximum magnification of 10,000 at the 1 Hz frequency (Kanao 1999).

A total of thirteen local events during 1990-2001 are listed in Table 1. The seismograms of the three components of the three recent events are shown in Fig. 1. The event on May 03, 1994, for instance, was not counted as a local event in previous studies by Kaminuma and Kanao (1997) because the event had a long duration of more than one minute with dominated by high frequency waveforms. However, it is clear from the three digital component seismograms by STS-1 that the event was a local event having clear P and S phases and S-P time of 16.2 S. The earthquake was the biggest one over the last twelve years from 1990 to 2001, with a magnitude of 1.4. The relatively large magnitude corresponds to the longer duration of this event. The magnitude of the earthquakes, in Table 1, was determined using the Japan Meteological Agency (JMA) method, which can be applied to the local events recorded on the three-component short period seismographs with velocity outputs such as HES at SYO.

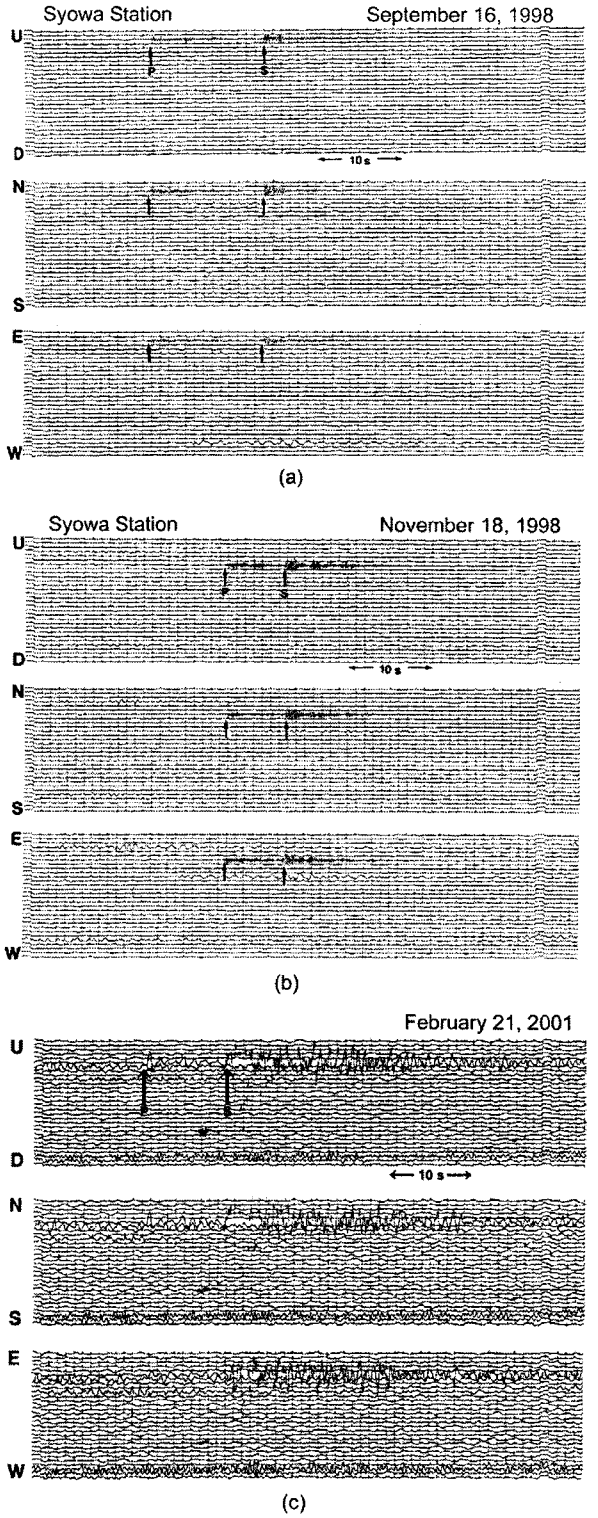

Fig. 1. A three component seismogram of the short period seismometer (HES) for local events occurring on (a) September 16, 1998, (b) November 18, 1998, (c) February 21, 2001.

3. Annual frequency

Fig. 2 shows the annual occurrences of local earthquakes detected at SYO from 1972 to 2001. The annual occurrences until 1990 were already reported by Kaminuma and Akamatsu (1992). The actual occurrences in 1972, 1973 and 1987 should be larger than those counted in the figure because the annual observation period for the three-year period was less than 12 months. As the magnifications of seismographs have changed about 10% through the whole observation period, this figure does not reflect exact numbers for local earthquakes occurring each year. However, the figure is enough to show the general trend in local seismic activities around SYO since the 1970's.

Kaminuma and Akamatsu (1992) had already reported six local earthquakes in 1990. However, a detailed reevaluation of the six events caused researchers to reach the conclusion that only one local earthquake had occurred in 1990. In the period of 1990-1996, nine local earthquakes of different types, including one event in 1990, were recorded. The seismicity during the period was very low and the magnitudes ranged from 0.1 to 1.4. These local seismic activities for the period 1990-1996 was lower than that for the period 1987-1989 when the tripartite seismic network was in operation. Relatively low activity in 1990-1996 was consistent with the idea that this period exhibited low seismic activity of an intermittent kind and that 1987-1989 was a high activity period, respectively (Kaminuma and Akamatsu 1992).

In the period 1997-2001, one local event was detected in 1997, two events in 1998 and one in 2001, respectively. The last event was recorded on February 21, 2001. The P-S time of the last event was 10.8 s on the three-component seismogram of the HES. The low seismic activity has continued until 2003.

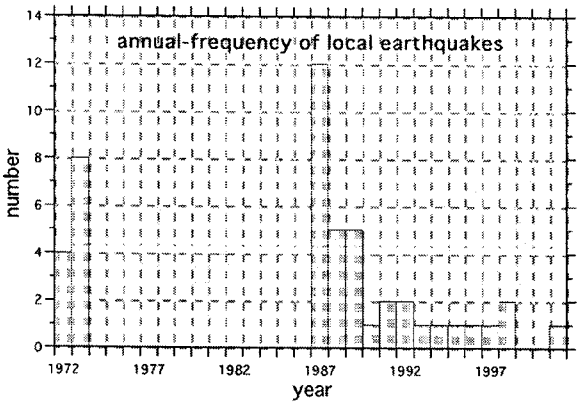

Fig. 2. Annual frequencies of local earthquakes observed at SYO since 1972.

4. Epicenter distributions

Earthquake locations were obtained by using tripartite observation network data during 1987-1989. Many different types of earthquakes, such as a mainshock-aftershock, twin earthquakes, earthquake swarms, etc., were detected and identified at that time. The earthquakes epicenters are

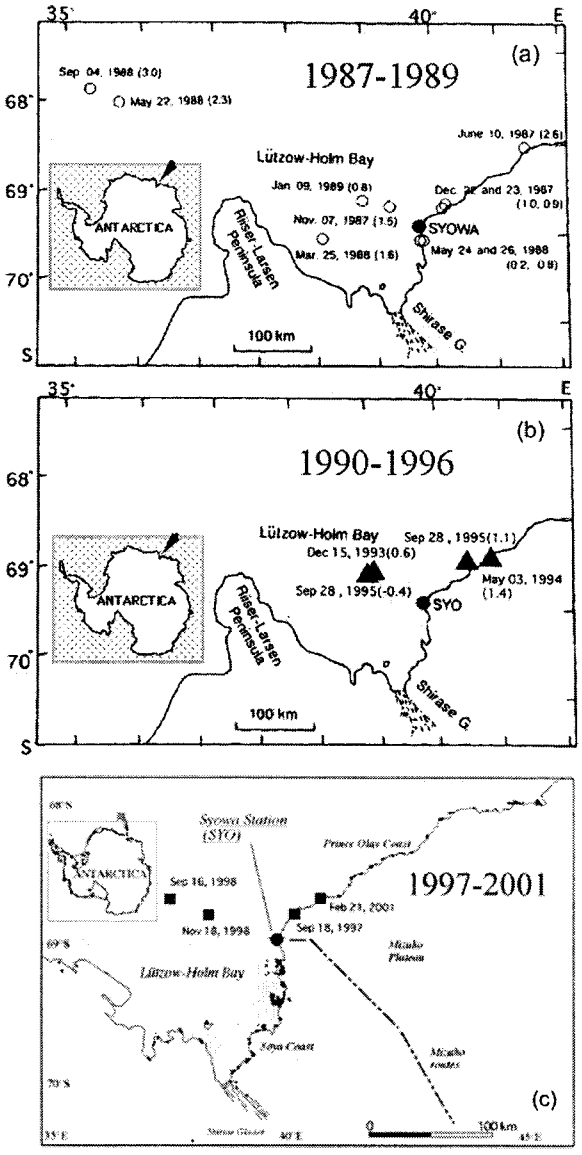

Fig. 3. Local earthquake locations around SYO of some magnitude. (a) 1987-1989, (b) 1990-1996, (c) 1997 -2001.

shown in Fig. 3(a). The obtained epicentral locations were concentrated on the two restricted areas around SYO. That is, one group was along the coast stretching from north to south crossing over the SYO, the other was located at the central part of the LHB (Kaminuma and Akamatsu 1992).

After 1990, epicenters for local events were determined by using the first particle motion of the initial phase and S-P time detected at only SYO. As the first arrival phases of the local events were considered to be the direct P phases, the propagating directions and incidence angles of the seismic waves were estimated by considering particle motions of the first arrival phases of three orthogonal components using digital seismograms. The propagating directions were determined by the horizontal trajectories. The incidence angles were determined by the vertical trajectories, which were projected on a vertical plane, including that of the epicenter and the station. The details of the location determination were already described by Kanao and Kaminuma (1995) and others. The propagating directions to SYO were also listed in Table 1. Epicentral distance was calculated by 'Oomori's formula' using 6.8 km/s as 'Oomori's constant'. This constant was estimated from the local crustal structure (Vp = 6.2 km/s, Vp/Vs = 1.95) proposed by Ikami *et al.* (1983).

For the period 1990-1996, Kaminuma *et al.* (1998) had already reported the epicenters of the four earthquakes among nine in Table 1 by using the above particle motion method. Fig. 3(b) shows the epicenter locations of the four local earthquakes determined by the single station method. Locations of the four earthquakes seem to be accurately estimated compared with the previous earthquake locations in 1987-1989. Epicenters of the local four events in 1997-2001 were also determined using the same methods (Fig. 3c). The earthquake locations generally coincide with the ones in 1987-1996.

5. Discussion

Some earthquakes have very similar waveforms to those of icequakes. In some cases, it is very hard to discriminate between the waveforms of earthquakes and icequakes. However, we have detected the local events with strict conditions for more than three decades. We have concluded that the occurrence of local events represents the actual tectonic signature around the SYO area, belonging to margins of the East Antarctic shield.

The local seismic activities around SYO, during 1990-2001, were very low compared with those of the previous three years in 1987-1989, when the tripartite seismic network had been operating. The detection capability of the teleseismic events at SYO in 1987-1993 was studied by Kanao and Kaminuma (1995). The local seismicity around SYO is thought to be the intermittent, because the number of local seismic events in 1987-1989 was larger than that of later years. This intermittent activity would be associated with the crustal uplift after deglaciation (Kaminuma and Akamatsu 1992; Kaminuma 1996; Kaminuma and Kimura 1997).

In recent years, there have been several reports presenting the local seismicity around Antarctica by temporary / permanent seismic networks (Bannister and Kennett 2002; Müller and Echstaller 2003; etc). Bannister and Kennett (2002) studied the seismicity around SBA and VNDA area through a temporary broadband seismic network. They found several interesting features, including the fact that a majority of the local events occurred along the coast, particularly in the vicinity of large glaciers. They proposed several causes for the occurrence of these events; basal sliding of the continental ice sheet, movement of the ice stream associated with several scales of glaciers, sea-ice origins, and the tectonic earthquakes. In order to distinguish the actual origins of these events, they mentioned the importance of determination the earthquake mechanism together with the depths of hypocenters. Müller and Echstaller (2003) have begun to operate the local seismic network around Neumayer Station. They also determined the hypocenters of local events along the coast and the mid-region surrounding the bay like our study area. Thus the earthquakes of LHB and those around the Neumayer Station are interpreted to be the result of post-glacial rebound.

A compilation of seismicity around the whole Antarctic continent has recently been reported by Kaminuma (2000) and Reading (2002). Kaminuma (2000) have classified the signature of seismicity for tectonic earthquakes into three groups; 1) the great earthquakes in the intraplate low seismic regions, 2) microseismic activity at the edge of the continent, and 3) relatively high seismic activity in Wilkes Land. Local seismicity around SYO, revealed by our study, is classified as group 2. Most of the local earthquakes in group 2 are presumably caused by tectonic stress accumulated with the crustal deformation after deglaciation. The effect of ice sheet changes originates from phenomena such as that of crustal deformation, earthquake occurrence, fault system, etc. in the shallow part of the lithosphere beneath the Antarctic.

6. Conclusions

This paper mentioned the characteristics of time series

for the occurrence of the local earthquakes around SYO, Western Enderby Land, over the past twelve years. The important results obtained here were summarized as follows:

1) Seismicity in 1987-1989: A tripartite seismic network had been operated around SYO in 1987-1989. Epicenters of local earthquakes were determined for the first time during a three-year period. Many different types of earthquakes, such as a mainshock-aftershock, twin earthquake, earthquake swarms, etc., were detected and identified at that time. The seismic activity during this period was higher than that of the following decade. Earthquake locations were concentrated along the coast and in the central part of the Lützow-Holm Bay.

2) Seismicity in 1990-1996 and 1997-2001: In the period of 1990-1996, nine local earthquakes were recorded with many different types of events. The seismic activity during the period was very low and the magnitudes ranged from 0.1 to 1.4. After the 1997 period, one local event was detected in 1997, two events in 1998 and one event in 2001, respectively. The low seismic activity has continued right up to 2003. Fairly low activity over the past decade was interpreted as an intermittent period occurring during deglaciation.

3) According to the data accumulated, it is possible to estimate the stress concentration relating to the glacial rebound around the Lützow-Holm Bay region. From 2002, continuous digital recording of the HES seismograph started at SYO. This enables us to determine the source mechanism of local events in the near future. Afterwards, it will eventually be possible to examine the relationship between the seismicity around Antarctica and deglacial phenomena such as crustal uplift and sea level change within the Earth environmental system.

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