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Seismicity in Antarctica and Local Earthquake Activities around Syowa Station, East Antarctica

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Abstract : Antarctica seems to be the only one seismic continent on the earth. No large earthquakes of which magnitude is larger than 5 have been located in the Antarctic continent, however, small- and micro-earthquake activities are detected by the world wide seismic network and the local network in the Antarctic. A tripartite seismic array was established in Syowa Station (69° S, 39° E)in 1987 for studying the local seismicity. Nine micro-earthquakes were recorded by the tripartite array during 19 months from June 1987 to December 1988. These earthquakes are located in the coastal area of the Antarctic continent and offshore. There are many well-developed elevated beaches and marine terraces in the coastal ice-free area of the Antarctic continent. These have been formed by the relative lowering of sea level, caused by the crustal uplift after the deglaciation. The local micro-earthquakes seem to have been caused by the tectonic stress which was accumulated by the slow-moving crustal uplift.

Key words : seismicity, crustal uplift, local earthquake, tectonic stress, deglaciation

Introduction

For the purpose of determining the locations of local earthquakes, which were estimated to occur around Japanese Antarctic Station, Syowa (69°S, 39°E) in East Antarctica, and the propagation characteristic of seismic waves under the east Antarctic continent, a large tripartite seismic network of radio-telemetry was established at Syowa Station in 1987 (Kaminuma and Akamatsu, 1987; Akamatsu et al., 1988). East Antarctica is one of the most stable shield continents on the earth. Some local tectonic earthquakes were recorded by the seismic network and are reported in this paper.

Earthquakes in the Antarctic Continent

Four earthquakes of 1918, 1920, 1952 and 1960 are held in the International Seismological Center (ISC) files for continental Antarctica by the early stage of the Antarctic Research. Only one of the locations, the event of 1952, was determined but without its magnitude. In the other three events, neither their locations nor their magnitudes were determined (Adams et al., 1985). Except for the event of 1952, no significant earthquakes were located on the Antarctic continent before the International Geophysical Year (IGY) of 1957 and 1958. About ten seismic stations have been operating on the Antarctic continent since the IGY and the occurrences there of small seismic events have been recognized on the seismograms at the stations (Hatherton, 1961; Hatherton and Evison, 1962; Browne-Cooper et al., 1967; Adams, 1969, and 1972).

Seven earthquakes were located by the seismic network on the Antarctic continent since IGY as shown in Figure 1 and Table 1. The first two events in Table 1 were located on Deception Island (64° S, 64° E), and occurred with volcanic eruptions. The other five events seem to be the tectonic earthquakes. Preliminary Determination of Epicenter Service (PDE) of the U.S. Geologcial Survey (USGS) reported that "these two hypocenters are belived to be the first instrumentally located in Antarctica".

One earthquake (body-wave magnitude 4.3) which occurred on June 26, 1968 was located on the Antarctic continent, near 20.3° W, 79.9° S (Kaminuma and Ishida, 1971). The P phase arrivals at five seismic stations on the Antarctic continent were used for the hypocenter determination. This is the first evidence of an earthquake occurrence in the Antarctic continent determined by the seismic network.

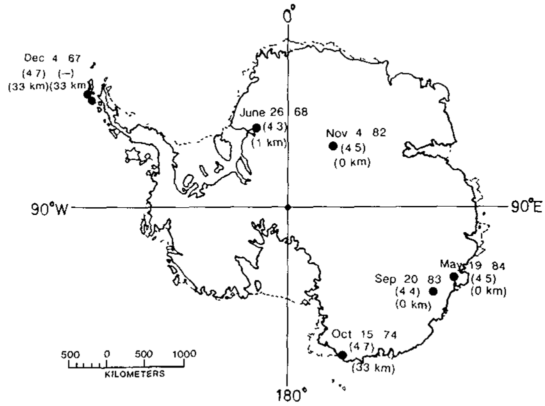

Fig. 1. The earthquake locations in the Antarctic Continent with body-wave magnitude and depth since IGY of 1957 and 1958.

Table 1. List of Earthquakes in the Antarctic continent.

Date	Time	Lat.	Long.	Depth	Mb Remarks
1967 Dec. 04	19th 00m 22.6s	63.0 S	60.5 W	33km	4.7 Volcanic eruption of Deception Island
	20h 28m 20.5s	63.2 S	60.3 W	33km	-USGS
1968 Jun. 26	18h 20m 52.8s	49.56S	20.33W	1km	4.3 Kamimura and Ishida (1971)
1974 Oct. 15	07h 31m 42.9s	70.55S	161.3 E	33km	4.7 Adams(1982)
1982 Nov. 04	00h 14m 19.2s	80.79S	36.9 E	0km	4.5 ISC, Adams et al. (1985)
1983 Sep. 20	03h 27m 15.5s	68.87S	122.1 E	0km	4.4 ISC
1984 May. 04	04h 01m 15.8s	67.49S	113.0 W	33km	4.9 ISC

An earthquake near the Oates Land Coast (70.5° S, 161.3° E) on October 15, 1974 was the first shock located on the Antarctic continent by the PDE of USGS and by the ISC. The earthquake was given body-wave magnitude of 4.9 by USGS and 4.7 by ISC. Adams (1982) reported that this event was located about 200 km southeast of the position of the 1952 earthquake of which relocation epicenter was 69.1±0.37° S, 158±2.3° E. He suggested that the occurrence of the two events might be taken to confirm earthquake activity on the Oates Land, but it might also be significant that the two locations were on the coast near a prominent glacier and ice tongue.

An earthquake of magnitude 4.5 in 1982 has been located by ISC, near 81° S, 37° E in the continental platform of east Antarctica, about 1,200 km from the location of the 1968 event. Adams et al. (1985) presented the report to attract attention to its occurrence.

Two earthquakes of body wave magnitude 4.4 and 4.5 have been located by ISC, in Wilkes Land, near the coast of the east Antarctic shield area, in 1983 and 1984. The locations of the above five events are given in Figure 1.

There are very few studies concerning microearthquakes in Antarctica. Kaminuma (1976) estimated by the routine seismic observation that the seismicity around Syowa Station in Lutzow-Holm Bay was less than one micro-earthquake per month. However its source location was not determined because of the inevitable difficulty coming from the single station observation.

Seismic Observation Network at Syowa Station

The seismic observation at Syowa Station was started by the 3rd Japanese Antarctic Research Expedition (JARE-3) in 1961 with a vertical components of HES short-period seismograph. Two horizontal-component seismographs were installed by JARE-5 in 1963 (Kaminuma et al., 1968). After four years of closure, Syowa Station was reopened in 1966 and the seismic observations with the three-component of HES short-period seismograph was continued during the year. In 1967, a three-component long-period seismograph of the Press-Ewing type was installed by JARE-8 and the seismic observations with the long- and short-periods seismographs have been continued since that time (Kaminuma et al., 1968). The phase readings of the seismic observation have been published by National Institute of Polar Research(NIPR), as a series of JARE Data Reports, "Seismological Bulletin of Syowa Station" since 1969.

As a new vault for seismographs was built at Syowa Station and the observations by three components long-period and short-period seismographs were started on March 1, 1970, the earthquake detection capability at Syowa Station has been improved by the observation in the new vault (Kaminuma and Chiba, 1973). The observations of a small tripartite seismic array with one-vertical seismograph had been carried out in East Ongul Island of Syowa Station in 1972-1973, 1977 and 1979. However, no significant seismic activities were reported. A tripartite seismic array with three-component seismographs was eastablished at Syowa Station in 1987 for studying the local seismicity around Syowa Station and the propagation characteristics of seismic waves under the east Antarctic shield area which is one of the most stable continents on the earth (Kaminuma and Akamatsu, 1987; Akamatsu et al., 1988), and the observation by the network has continued until the end of 1989.

The seismic observation network consisted of three sites with a three-component 1-s seismograph; Syowa Station (SYO), Tottuki Point (TOT) and Langhovde (LAN) as shown in Figure 2. TOT and LAN were located on the outcrops at the edge of the east Antarctic shield. Those two stations were linked by radio-telemetry to Earth Science Laboratory of Syowa Station. The distances between the sites ranged from 15 to 30 km.

A smaller tripartite array with three 1-s vertical seismographs had been operated in East Ongul Island from February 1988 to December 1989. The distances between the three sites, denoted E, S and W in Figure 2, were about 1 km.

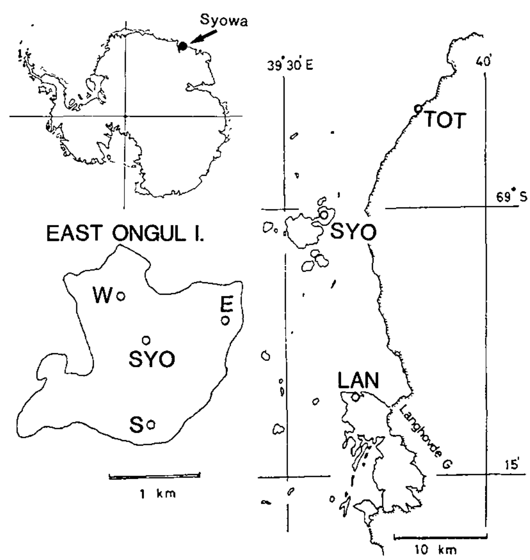

Fig. 2. The tripartite seismic array with three-component seismographs around Syowa Station operated from June 1987 to October 1989. The small tripartite array (W, S and E) in East Ongul Island was occupied from February 1988 to December 1989.

The seismic signals were transmitted by cable wire to the recording system at Earth Science Laboratory (Akamatsu et al., 1989).

Seismic Activity

More than 12,000 events were recorded during 19 months from June 1987 to December 1988. About 35 percent of the total events were sea-ice shocks, 55 percent were icequakes, 8 percent were teleseisms and 2 percent were the events caused by glacier movements. Only nine local events were detected by the system during the 19 months as listed in Table 2 and shown in Figure 3.

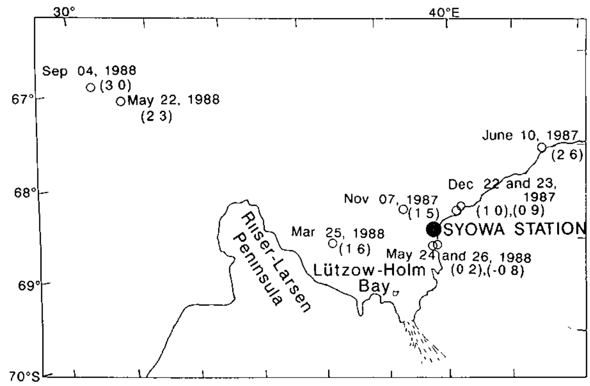

Fig. 3. The locations of local earthquakes with magnitude around Syowa Station recorded from June 1987 to December 1988.

Table 2. List of Local Earthquakes around Syowa Station.

Date	Time	Magnitude	Source region
Jun. 10 1987	1936	2.6	Prince Olav Coast, 170km NE of SYO
Nov. 07	0623	1.5	Lützow-Holm Bay, 50km NW of SYO
Dec. 22	1136	1.0	Near Tama Glacier, 50km NE of SYO
23	0654	0.9	ditto
Mar. 25, 1988	1516	1.6	Western part of Lützow-Holm Bay, 120km WNW of SYO
May 22	0258	2.3	NW off Riiser-Larsen Peninsula, 350km NW of SYO
May 24	2303	0.2	The mouth of Langhovde Glacier, 20km SSE of SYO
26	2306	-0.8	
Sep. 04	1723	3.0	NW of Riiser-Larsen Peninsula, 400km NW of SYO

Five events out of nine are located along the Prince Olav Coast, two are in Lützow-Holm Bay and the others are in the northwestern offing of the Riiser-Larsen Peninsula. Akamatsu et al. (1989) determined the magnitudes of the events in Table 2 by the formula for shallow events presented by Watanabe (1971). The magnitude ranges from -0.8 to 3.0, but most of them are micro-earthquakes in the range of 1.0−3.0.

Magnitudes of the two events on May 24 and 26, 1988 located near the Langhovde glacier are 0.2 and -0.8, the ultramicro-earthquakes. The seismograms of these two events at SYO are shown in Figures 4a and 4b. As clear phases with amplitude larger than 50 μcm/s are recorded at the distant stations of SYO and TOT, the two events must not have been icequakes but earthquakes with no doubt. The apparent velocity of P phase observed by the small tripartite network in East Ongul Island is 6.5 km/s. This velocity is too high for the velocity of a shallow event. Estimating from the apparent velocity of 6.5 km/s, the depth of the event is deeper than five kilometers at least. The event occurred in the second layer of the upper crust presented by Ikami et al. (1984). The second event of May 26 must be the aftershock of the first event judging from their magnitudes. The wave forms at SYO of the Nov. 7, 1987 event located in Lützow-Holm Bay are given in Figure 5. Three aftershocks of this event were recognized on the seismograms of the routine seismic observation, but were not clear on those of the tripartite network due to extreme noise. Those two events show that there are activities of the main shock-after shock type among the micro-

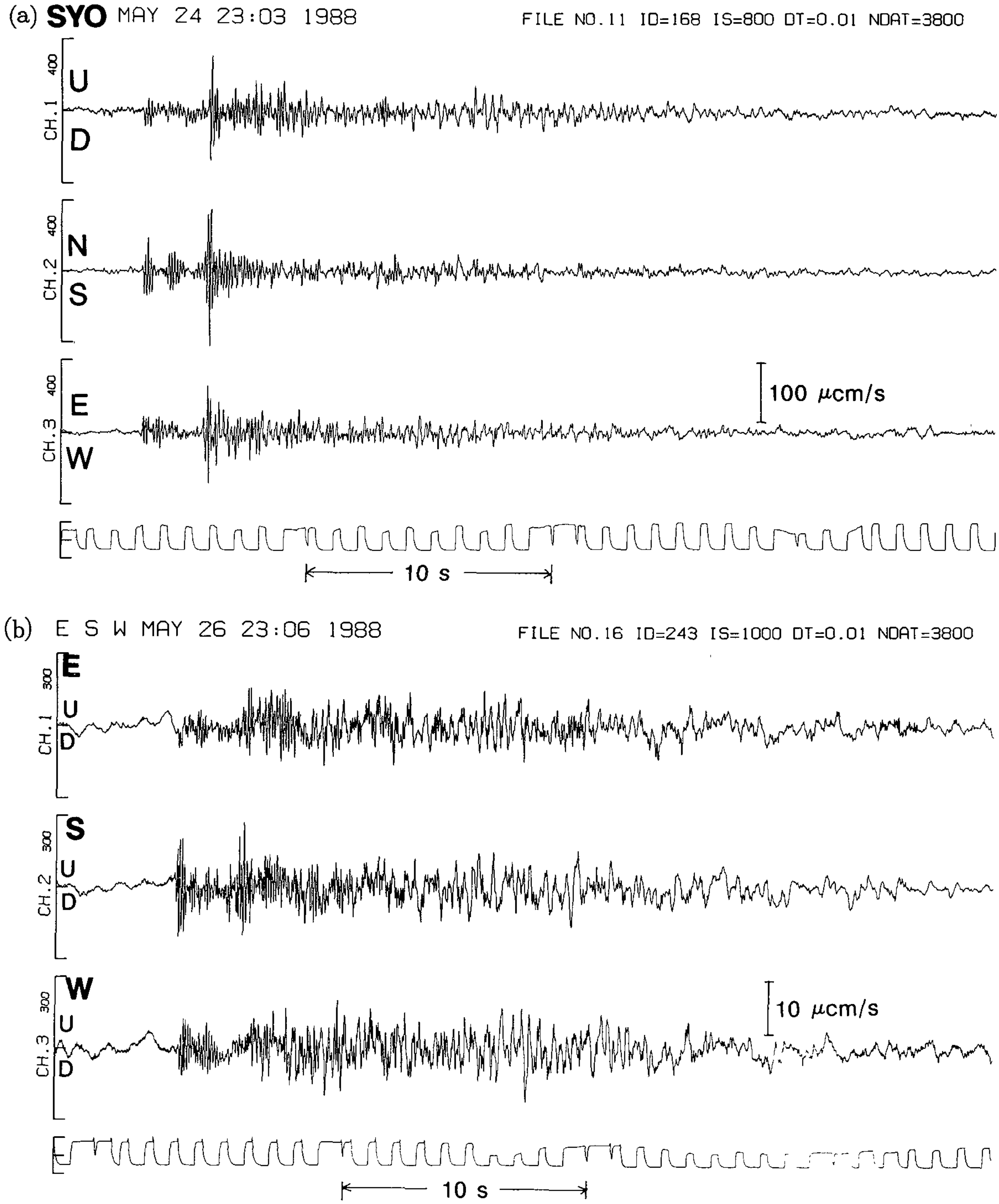

Fig. 4. (a) The seismogram of the event of May 24, 1988 recorded by the small tripartite array.
(b) Three-component seismograms of the event of May 26, 1988 at Syowa Station.

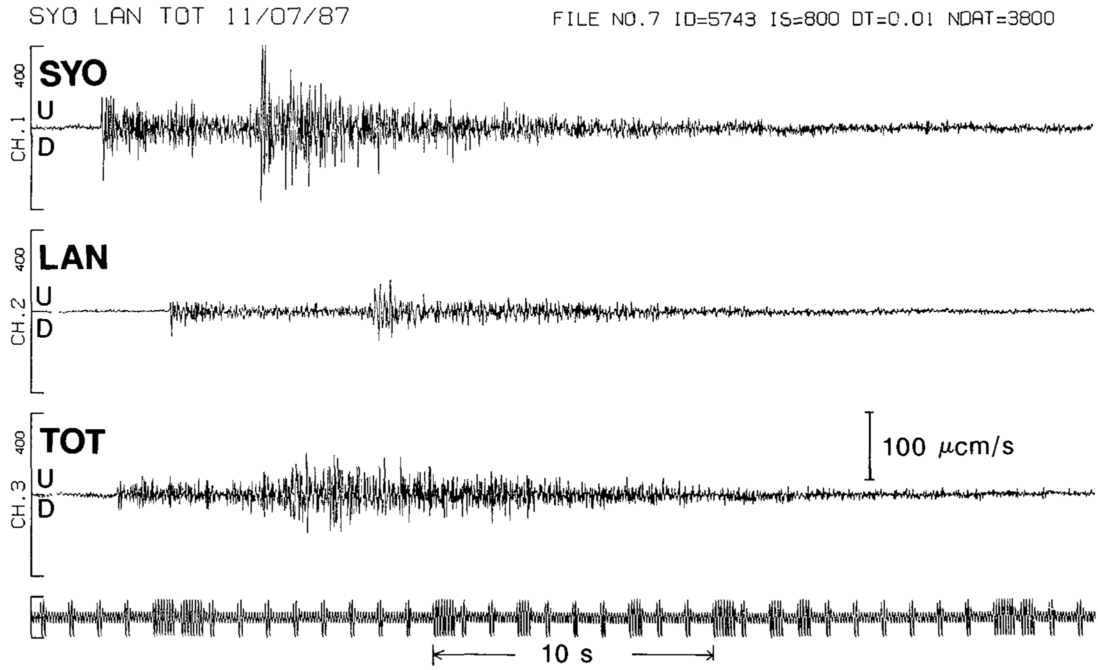

Fig. 5. Vertical component seismograms recorded at SYO, LAN and TOT on November 7, 1987.

seismic activities around Syowa Station.

Figure 6 shows the three-component seismograms of the earthquake of June10, 1987 at SYO, which has about 20s S-P time and magnitude of 2.6 at Syowa Station. It must be pointed out strongly that nine events with similar wave forms were recorded during the preliminary observation period from March to May 1987, but no such events were recorded after the June 10 event. Akamatsu et al. (1988) mentioned that those earthquakes are located in the boundary between the two geological complexes, Lützow-Holm Complex and Layner Complex. The earthquakes are considered tectonic earthquakes occurring along the geological fault, and a kind of earthquake swarms.

Two events of Dec. 22 and 23, 1987 located near TOT are almost the same in magnitude, being 1.0 and 0.9. Their wave forms are very similar as shown in Figures 7a and 7b. From the above facts, the two events are probably a multiple shock.

Two events of Nov. 7, 1987 and Mar. 25, 1988 in Lützow-Holm Bay, shown in Figure 3, seemed similar to the events reported by Kaminuma (1976). The events located in the northwestern offing of the Riiser-Larsen Peninsula have relatively large magnitudes among the earthquakes detected by the network. As the earthquakes which occurred in the area were far from the network, only the ones with magnitude larger than about 3 (small earthquake) might have been detected.

There are many types of earthquakes, such as the earthquake swarms, the main shock-after shocks, multiple shock, etc. occurred around Syowa Station, even the seismic activity is very low. This pattern of seismic activity around Syowa Station is similar to the activities in Japan where it has the highest seismicity on the earth.

Figure 8 shows annual number of microearthquakes counted on the seismograms of the routine observation and the tripartite seismic

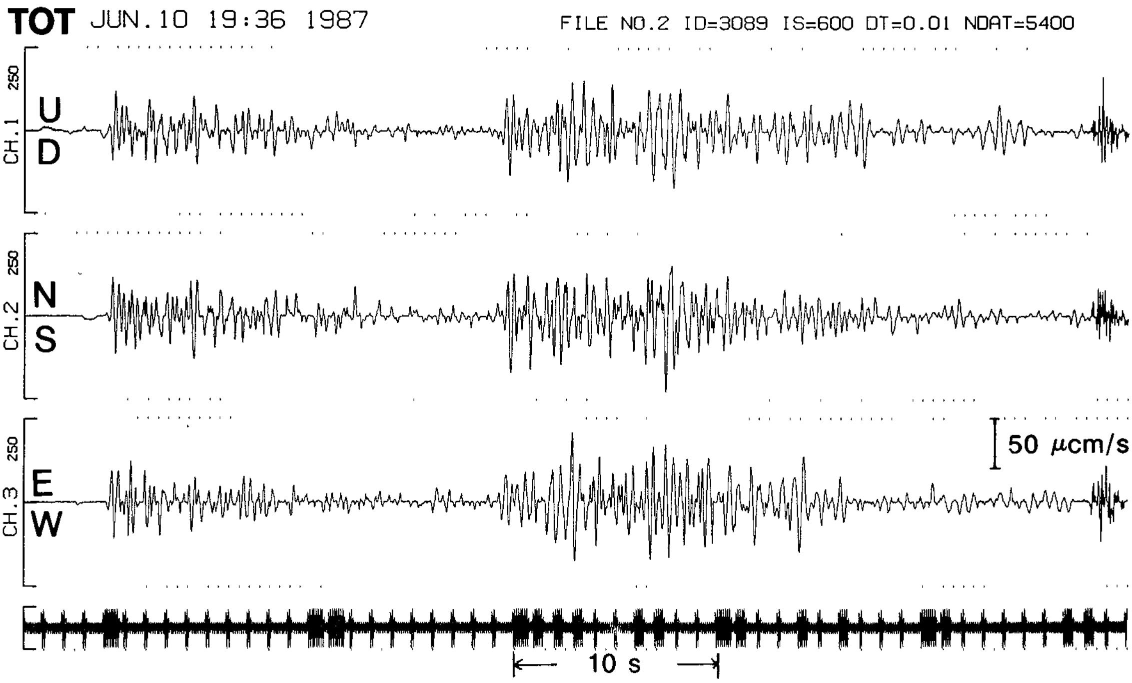

Fig. 6. Three-component seismograms of the event of June 10, 1987 at SYO.

array at Syowa Station from 1972 to 1988. As the magnification of seismographs are not the same through the period, the figure does not show the seismicity but minimum number of micro-earthquakes detected on the seismograms. The arrows in Figure 8 indicate the number of earthquakes that occurred is more than that shown in the figure. The solid lines in 1976 and 1979−1982 show the period that no micro-earthquakes were detected because seismologists were wintering during that time and scaled seismogram carefully. The earthquakes occurred only in 1972−73 and 1987−88. It must be pointed out from the figure that the micro-earthquakes occur intermittently in and around Syowa Station.

Discussion

There are many well-developed elevated beaches and marine terraces in the broad coastal ice-free areas of the Antarctic continent. The well-developed elevated beaches and the marine terraces are found around Syowa Station and along the eastern coast of Lützow-Holm Bay. These elevated beaches and marine terraces have been formed by the relative lowering of sea level (Omoto, 1977; Yoshida and Moriwaki, 1979), caused by the crustal uplift after the deglaciation. The maximum heights of elevated beaches around Syowa Station are 22 m in East Ongul Island, 19 m in Teöya (Island), 3 km south from East Ongul Ialand, and 35 m in Ongulkalven (Island), 5 km west from East Ongul Island as shown in Figure 9. No elevated beaches are found in West Ongul Island. The origin of the horizontal axis in Figure 9 is taken at the edge of the continent where is at the front of the Antarctic ice sheet.

The uplift movement seems a block movement: the height of the elevated beaches increases according to the distance from the edge

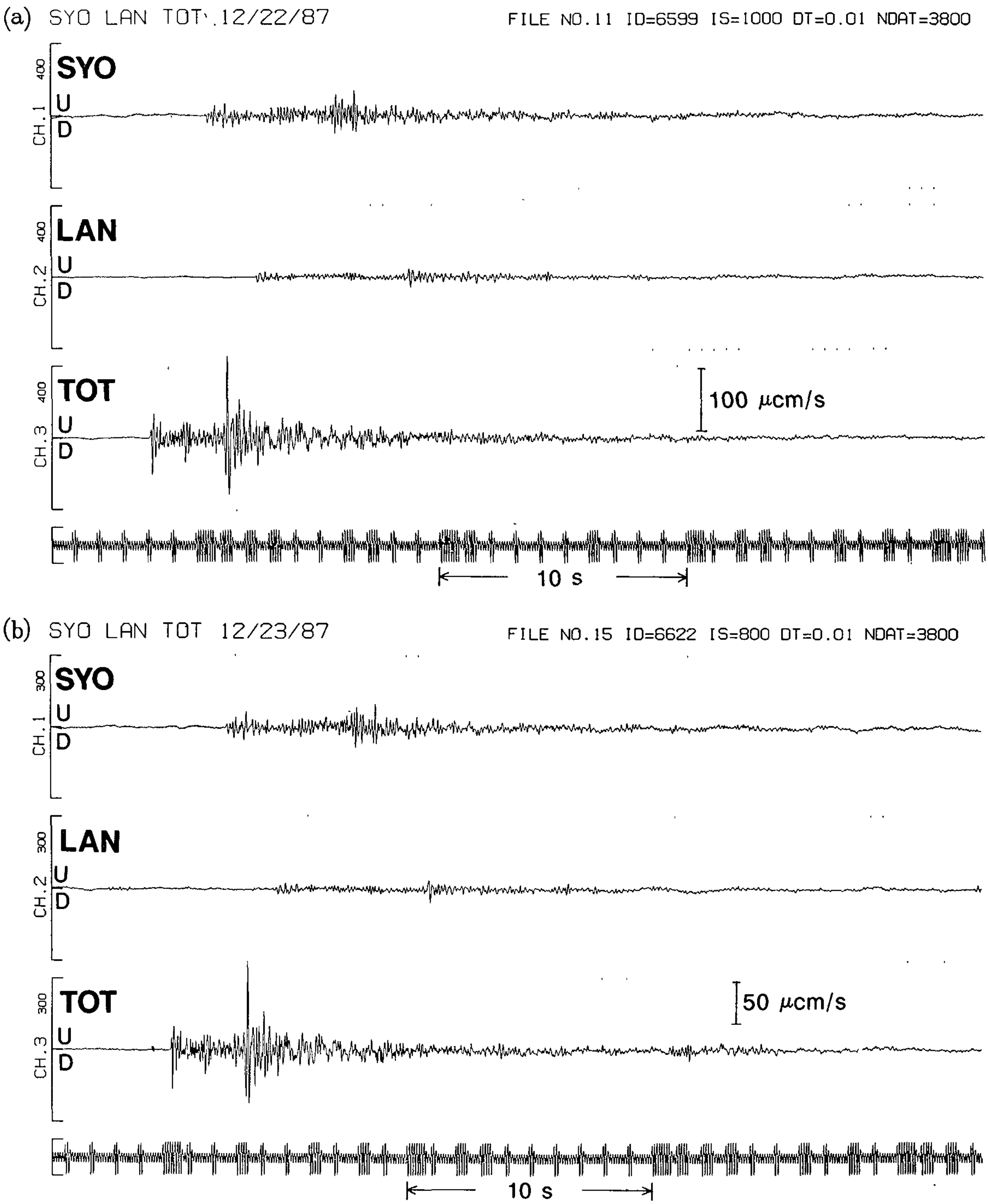

Fig. 7. Vertical component seismograms recorded at SYO, LAN and TOT on December 22, 1987 (a), and on December 23 (b).

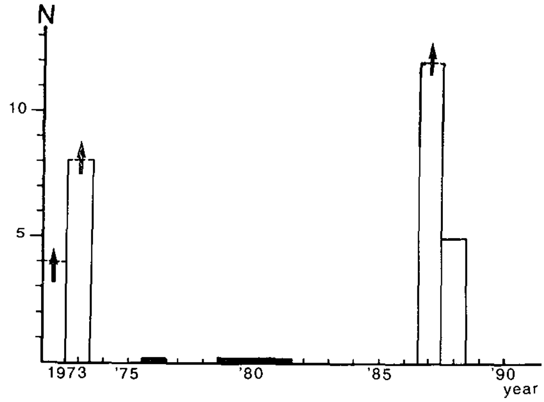

Fig. 8. Annual number of earthquakes around Syowa Station counted on the seismograms of the routine observation and the tripartite array from 1972 to 1988.

of the continent and each beach is horizontal. The uplift movement of the Ongulkalven block in Figure 9 is more than that of the East Ongul-Teöya block. As there is the Ongul strait, 4 km

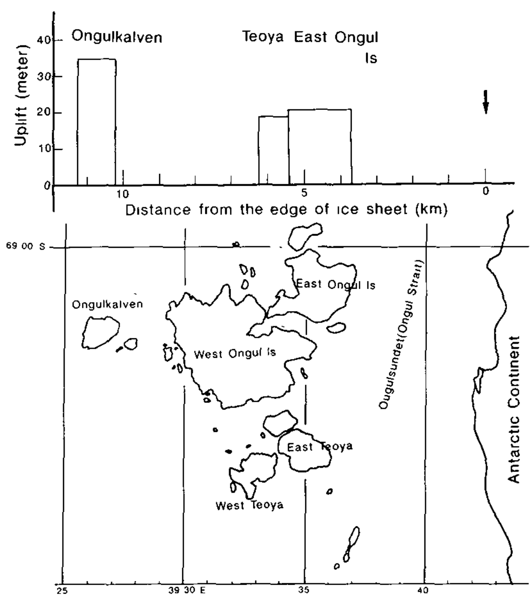

Fig. 9. The maximum heights of elevated beaches around Syowa Station.

in width and 700 m in depth between the East Ongul-Teöya block and the continent, the movement of East Ongul-Teoya block is independent from that of the continent.

As the dates of submarine fossils found in East Ongul Island are about 6,000 years BP, the rate of the uplift of the submerged areas relative to the sea level seems to be 2.5 mm/yr on the average, possible maximum being 5-6 mm/yr (Yoshida and Moriwaki, 1978). The crustal uplift seems to have continued during the last 6,000 years. Kaminuma (1990) estimated that the micro-earthquake around Syowa Station have been caused by the tectonic stress which was accumulated by the slow-moving crustal uplift after the deglaciation.

Considering the above mentioned facts, a process of the micro-earthquake activities around Syowa Station is investigated as follows:

1. Micro-earthquakes around Syowa Station are caused by the tectonic stress which was accumulated by the crustal uplift after the deglaciation, because the locations of the earthquakes are in the coastal and offshore area.

2. The crustal uplift is not a linear phenomena but a block movement, because the locations of epicenters are in the coastal and offshore area, and the height of the elevated beaches increases according to the distance from the continental edge.

3. The tectonic stress accumulated among the block boundaries, and the earthquakes are caused by the stress.

4. As the rate of stress accumulation is very slow, no larger earthquakes occur and only micro-earthquakes occur in the coastal area.

5. The crustal uplift continued only 1-2 years during about one decade and/more. Micro-earthquakes occur to correspond with the intermittent crustal uplift.

In conclusion, the local earthquakes mentioned in this paper have been caused by the tectonic stress which was accumulated by the slow moving crustal uplift after the deglaciation.

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