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# INTERMITTENT MICRO-SEISMIC ACTIVITIES AROUND SYOWA STATION, EAST ANTARCTICA

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***Abstract:*** Antarctica seems to be the only one aseismic continent on the earth. No large earthquakes of which magnitude is larger than 5 have been located in the Antarctic Continent, although, small and micro-earthquake activities are detected by the worldwide seismic network and some local networks in the Antarctic. A tripartite seismic array was established at Syowa Station (69°S, 39°E) in 1987 for studying the local seismicity. Ten micro-earthquakes were recorded by the tripartite array during 19 months from June 1987 to January 1989. These earthquakes are located in the geological and geophysical structural boundaries of the coastal area in the Antarctic Continent and offshore. Other four earthquakes were recorded during 9 months from February to October, 1989. The local earthquakes around Syowa Station occurred intermittently. 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. As local earthquakes occur intermittently, it seems that the crustal uplift is not a linear movement but an intermittent one, and the local earthquakes occur corresponding with the intermittent crustal uplift.

## 1. Introduction

East Antarctica is one of the most stable shield continents on the earth. KAMINUMA (1976) estimated by the routine seismic observation that the seismicity around Japanese Antarctic Station, Syowa (69°S, 39°E) in Lützow-Holm Bay, East Antarctica 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.

For the purpose of determining the locations of local earthquakes which were estimated to occur around Syowa Station and the propagation characteristics 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). Some local tectonic earthquakes were recorded by the seismic network. The occurrence mechanism of the local tectonic earthquakes around Syowa Station is discussed in this paper.

## 2. 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 the vertical component of HES short-period seismograph. Two horizontal-component seismographs were installed by JARE-5 in 1963 (ETO, 1962; 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 were 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 seismic signals of the both type seismographs were recorded on 35 mm film. The phase readings of the seismic observation have been published by National Institute of Polar Research, as a series of JARE Data Reports, "Seismological Bulletin of Syowa Station" since 1969.

The earthquake detection capability at Syowa Station has been improved, because a new vault for seismographs was built at Syowa Station and the observations by three-component long-period and short-period seismographs in the vault were started on March 1, 1970 (KAMINUMA and CHIBA, 1973).

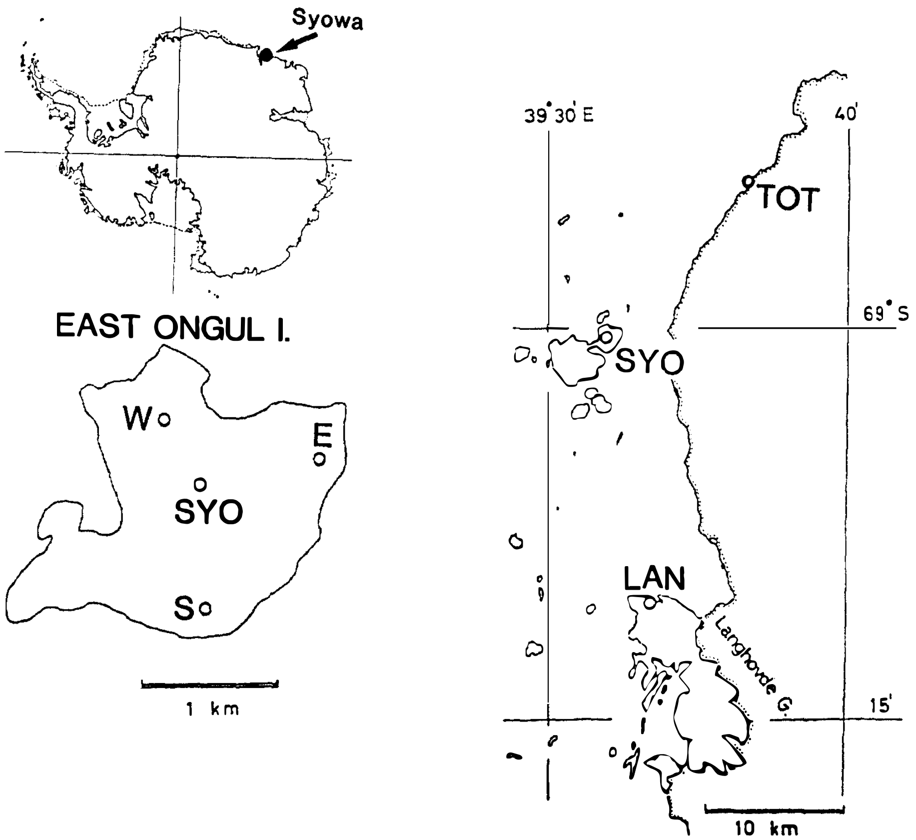


*Fig. 1. The tripartite seismic array with three-component seismographs around Syowa Station operated from June 1987 to October 1989. The small tripartite array (W, S and E) in East Ongul Island was occupied from February 1988 to December 1989.*

The observations of a small tripartite seismic array with one-vertical seismographs had been carried out at Syowa Station, East Ongul Island, in 1972–1973, 1977 and 1979. However, no significant seismic activities were reported. A tripartite seismic array with three-component seismographs was established 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 (KAMINUMA and AKAMATSU, 1987; AKAMATSU *et al.*, 1988). The observation by the network was 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 Fig. 1. TOT and LAN were located on the outcrops at the edge of the East Antarctic Continent. Those two stations were linked by radiotelemetry to Earth Science Laboratory of Syowa Station. The distances between the sites ranged from 15 to 30 km (AKAMATSU *et al.*, 1988).

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 Fig. 1, were about 1 km. The seismic signals were transmitted by cable wire to the recording system at Earth Science Laboratory (AKAMATSU *et al.*, 1989).

## 3. Seismic Activity

More than 17000 events were recorded during 29 months from June 1987 to October 1989. About 25% of the total events were sea-ice shocks, 66% were ice-quakes, 8% were teleseisms and 1% was the events caused by glacier movements. Only ten local events were located by the system during the first 20 months from June 1987 to January 1989 as listed in Table 1 and shown in Fig. 2.

Five events out of ten are located along the Prince Olav Coast, three 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 1 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.

*Table 1. List of local earthquakes around Syowa Station.*

| Date | | | Time | Magnitude | Source region |
|---|---|---|---|---|---|
| June | 10, | 1987 | 1936 | 2.6 | Prince Olav Coast, 170 km NE of SYO |
| November | 7 | | 0623 | 1.5 | Lützow-Holm Bay, 50 km NW of SYO |
| December | 22 | | 1136 | 1.0 | Near Tama Glacier, 50 km NE of SYO |
| | 23 | | 0654 | 0.9 | ditto |
| March | 25, | 1988 | 1516 | 1.6 | Western part of Lützow-Holm Bay, 120 km WNW of SYO |
| May | 22 | | 0258 | 2.3 | NW off Riiser-Larsen Peninsula, 350 km NW of SYO |
| | 24 | | 2303 | 0.2 | The mouth of Langhovde Glacier, 20 km SSE of SYO |
| | 26 | | 2306 | −0.8 | ditto |
| September | 4 | | 1723 | 3.0 | NW of Riiser-Larsen Peninsula, 400 km NW of SYO |
| January | 9, | 1989 | 0313 | 0.8 | Lützow-Holm Bay, 80 km WNW of SYO |

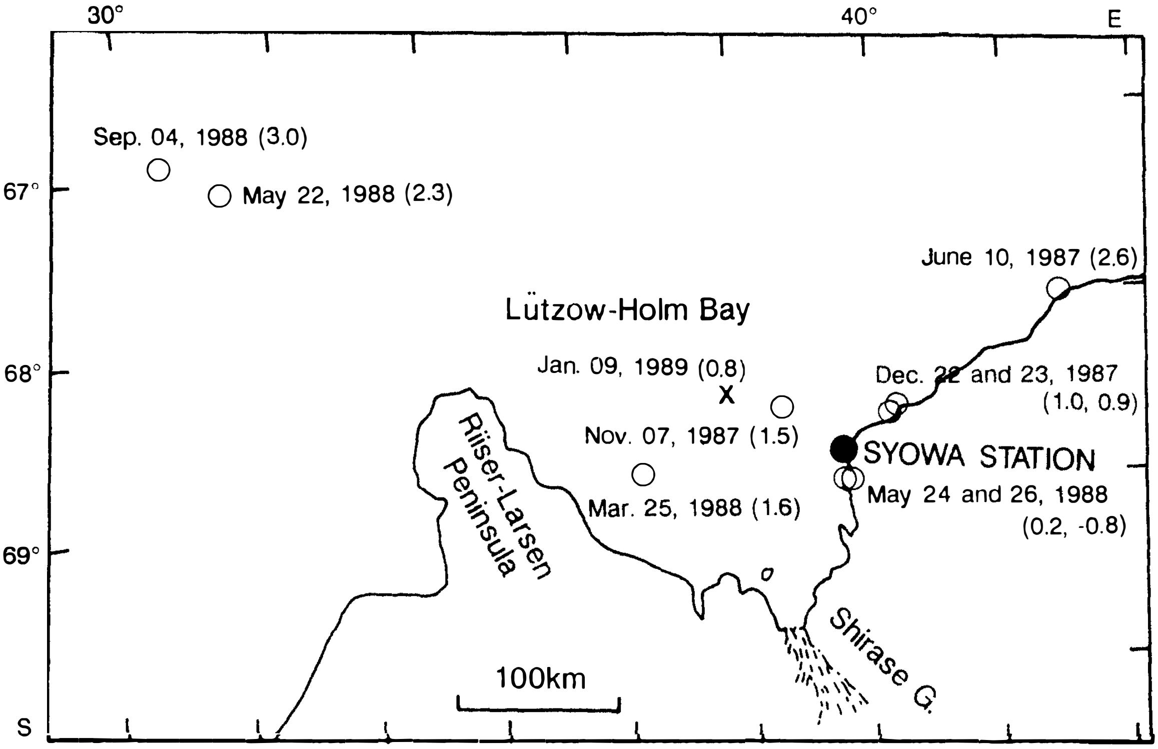


*Fig. 2. The locations of local earthquakes with magnitude around Syowa Station recorded from June 1987 to January 1989.*

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 event of May 26 is estimated to be the aftershock of the event of May 24 judging from their magnitudes (AKAMATSU *et al.*, 1989). Three aftershocks of the November 7, 1987 event were recognized on the seismograms of the routine seismic observation, but were not clear on the tripartite network due to extreme noise. Those three events show that there are the activities of the main shock–aftershock type among the micro-seismic activities around Syowa Station (AKAMATSU *et al.*, 1989). Three events of November 7, 1987, March 25, 1988 and January 9, 1989 in Lützow-Holm Bay looked similar to the events reported by KAMINUMA (1976) from their locations.

The earthquake of June 10, 1987 has about 20 s S-P time at Syowa Station and magnitude of 2.6. It should be emphasized 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 to be tectonic earthquakes occurring along the geological fault, and a kind of earthquake swarms.

Two events of December 22 and 23, 1987 located near TOT are almost the same in magnitude, being 1.0 and 0.9 and their wave forms are very similar to each other. From the facts, the two events are probably a multiple shock.

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 some different types of earthquakes, such as the earthquake swarm, the main shock-after shocks, multiple shock, etc., occurring around Syowa Station, even the seismic activity is very low. This pattern of seismic activities around Syowa Station is similar to the activities in Japan where is the most high seismicity on the earth.

Four events were detected on the monitor seismogram during 9 months from February to October 1989 but their locations were not determined because the observation of the large tripartite network did not work well at that stage. The list of the five events in 1989 is given in Table 2. The three-component seismograms of the June and 6 November 26 events at Syowa Station are shown in Figs. 3 and 4. As S-P time

*Table 2. Local earthquakes around Syowa Station in 1989.*

| Date | | Phase | Time | | S-P (s) |
|---|---|---|---|---|---|
| January | 9 | EPZ | 0313 | 40.2 | 7.5 |
| June | 6 | EPZ | 0841 | 33.2 | 16.8 |
| November | 26 | EPZ | 2318 | 15.1* | 16.4 |
| December | 26 | EPZ | 0215 | 13.2 | 13.5 |
| | 29 | EPZ | 1748 | 08.4 | 13.5 |

* Exact time is not determined due to recording trouble.

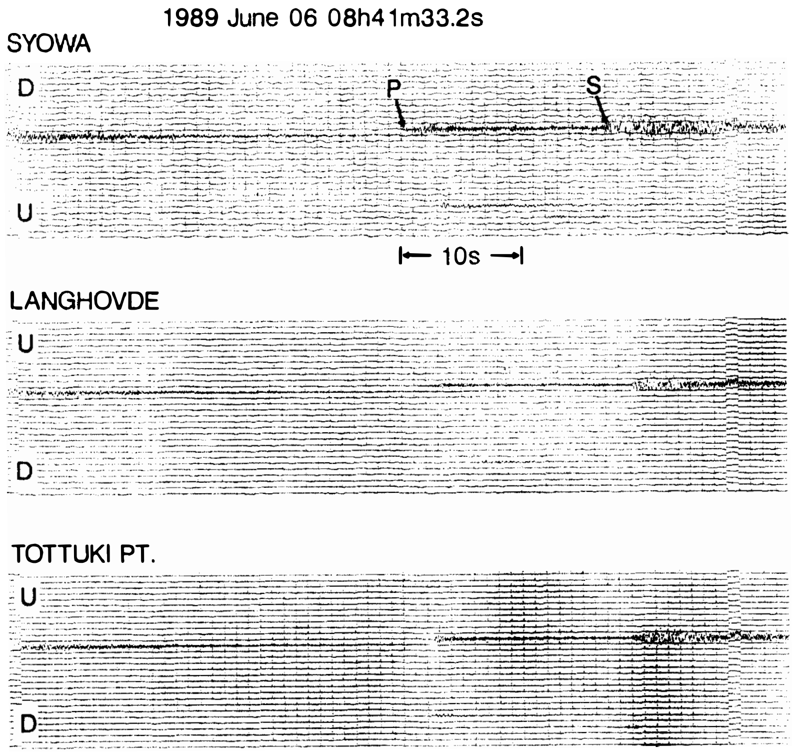


*Fig. 3. Vertical-component seismograms of the event of June 6, 1989 at Syowa Station, Langhovde and Tottuki Point.*

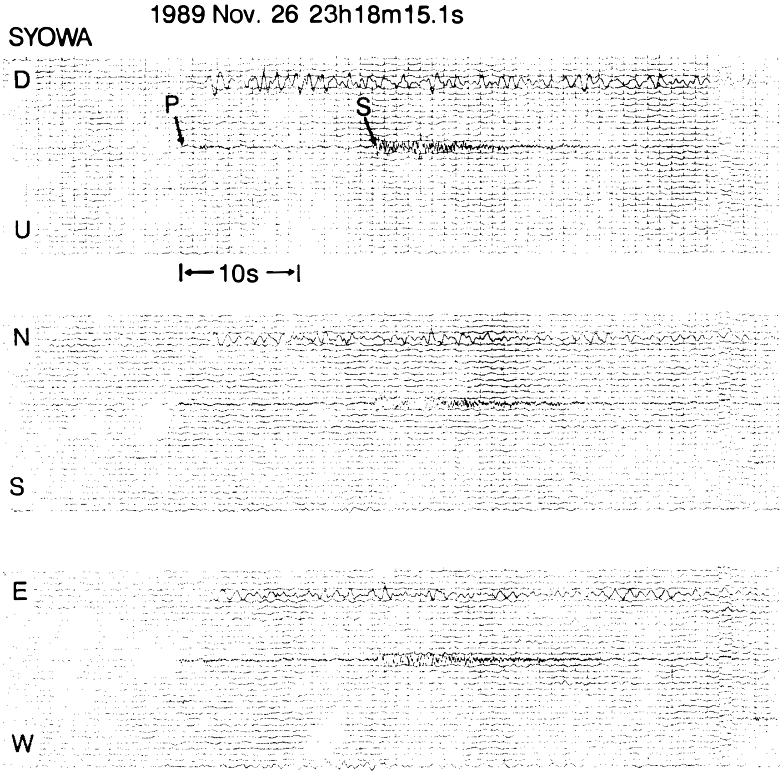


*Fig. 4. Three-component seismograms of the event of November 26, 1989 at Syowa Station.*

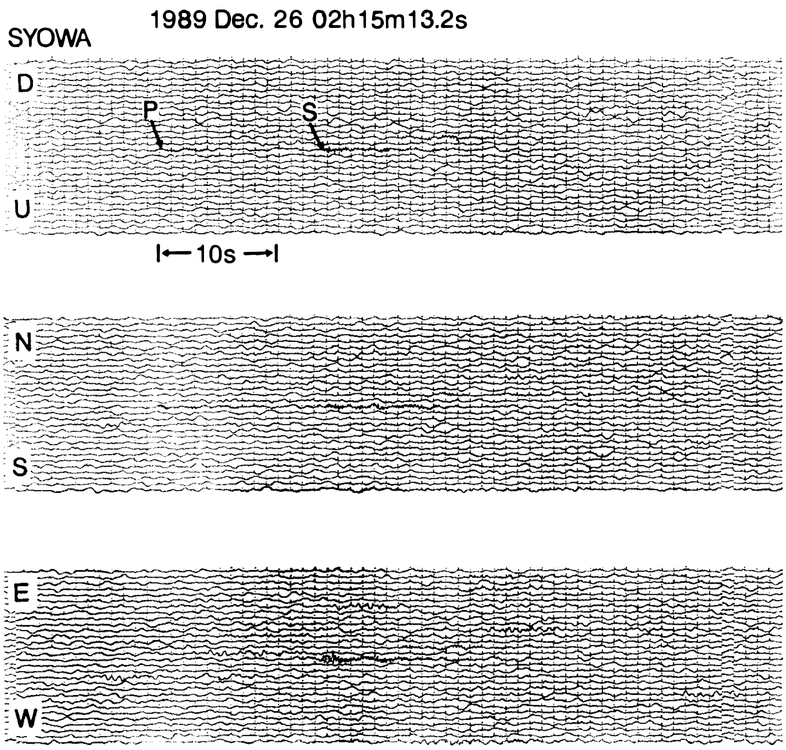


*Fig. 5. Three-component seismograms of the event of December 26, 1989 at Syowa Station.*

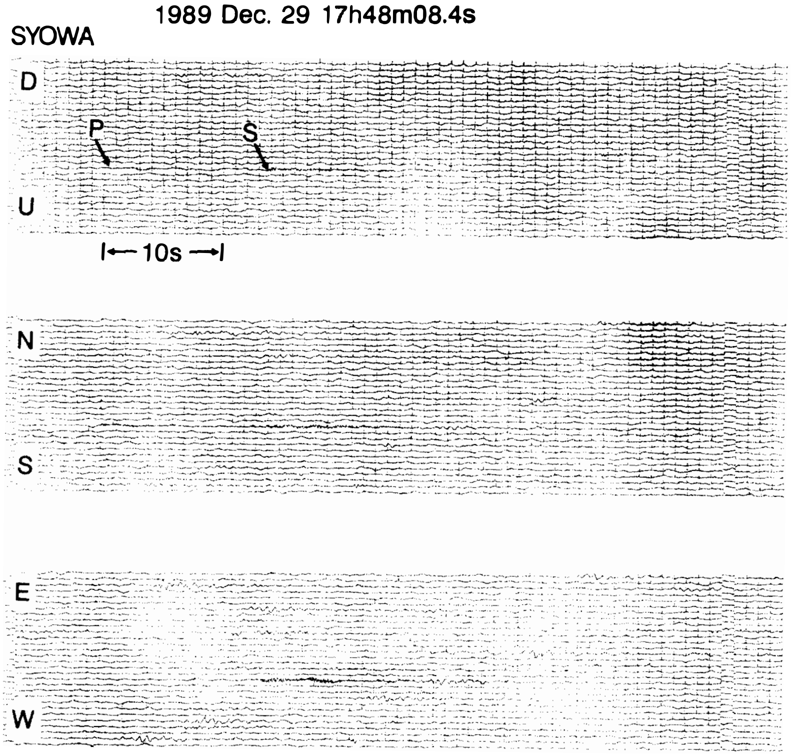


*Fig. 6. Three-component seismograms of the event of December 29, 1989 at Syowa Station.*

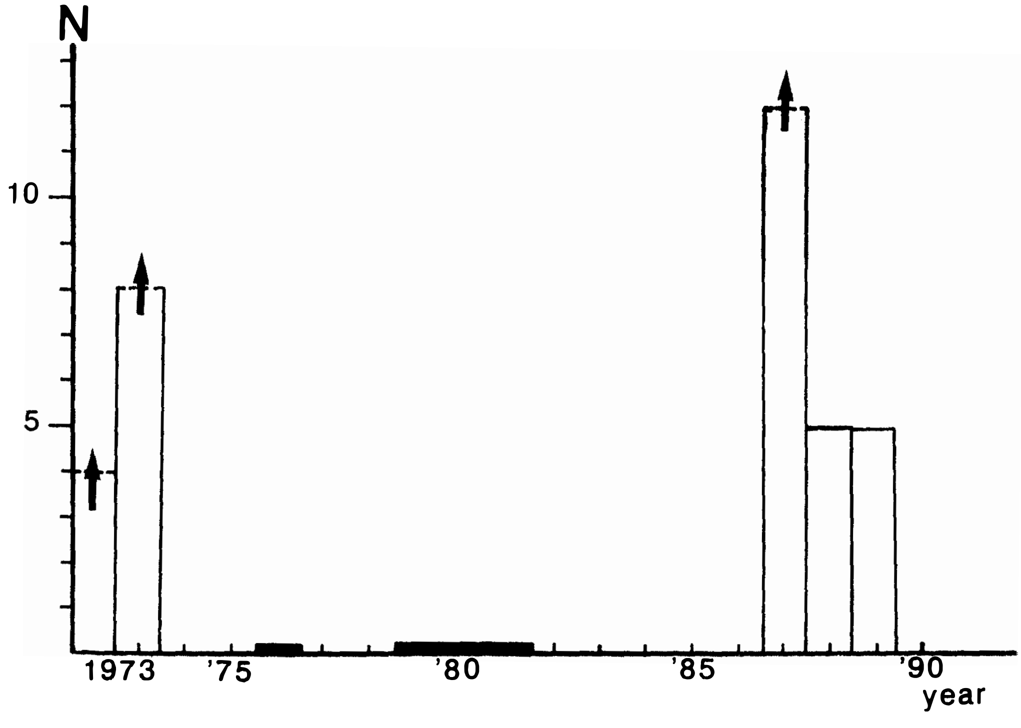


*Fig. 7. Annual number of earthquakes around Syowa Station counted on the seismograms of the routine observation and the tripartite array from 1972 to 1989.*

of these two events is nearly the same and their wave forms are very similar, the two events must be located in the same area.

The seismograms of the events of December 26 and 29 are shown in Figs. 5 and 6. For the reason of the events of June 6 and November 26 similar wave forms and nearly same S-P time, the two events are also located in the same area.

Figure 7 shows annual number of micro-earthquakes counted on the seismograms of the routine observation and the tripartite seismic array at Syowa Station from 1972 to 1989. As the magnification of seismographs is not the same throughout the period, the figure does not show the seismicity but minimum number of local earthquakes detected on the seismograms. The arrows in Fig. 7 indicate that the number of earthquakes occurred is more than that shown in the figure. The solid line in 1976 and 1979–1982 show the periods when no local-earthquakes were detected in spite of the fact that seismologists were wintering during that time and scaled seismogram carefully. The earthquakes occurred only in 1972–73 and 1987–89. It must be pointed out from the figure that the local-earthquakes occur intermittently in the vicinity of Syowa Station.

## 4. Discussion

There are many well-developed elevated beaches and marine terraces in the broad coastal ice-free areas of the Antarctic Continent, as seen 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; YOSHSIDA 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 Island, and 35 m in Ongulkalven (Island), 5 km west from East Ongul Island as shown in Fig. 8. Those in West Ongul Island are not measured at this stage. The origin of the horizontal axis in Fig. 8 is taken at the edge of the continent where is the front of the Antarctic ice sheet.

The uplift movement seems a block movement, because the height of the elevated beaches increases according to the distance from the edge of the continent and each beach is horizontal. The uplift movement of the Ongulkalven block in Fig. 8 is larger than that of the East Ongul-Teöya block. As there is the Ongul Strait, 4 km wide and 700 m deep, between the East Ongul-Teöya block and the continent, the movement of East Ongul-Teöya block is independent of that of the continent.

As the ages of submarine fossils found in East Ongul Island are about 6000 years BP, the rate of the uplift of the submerged areas relative to the sea level seems to be 2.5 mm/y on the average, possible maximum being 5–6 mm/y (YOSHIDA and MORIWAKI, 1979). The crustal uplift seems to have continued during the last 6000 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.

As shown in Fig. 2, the local earthquakes are located at the mouths of glaciers in the coastal area. There is a geological boundary located in the center part of Lützow-Holm Bay (HIROI *et al.*, 1991) and a clear boundary of Bouguer gravity anomaly

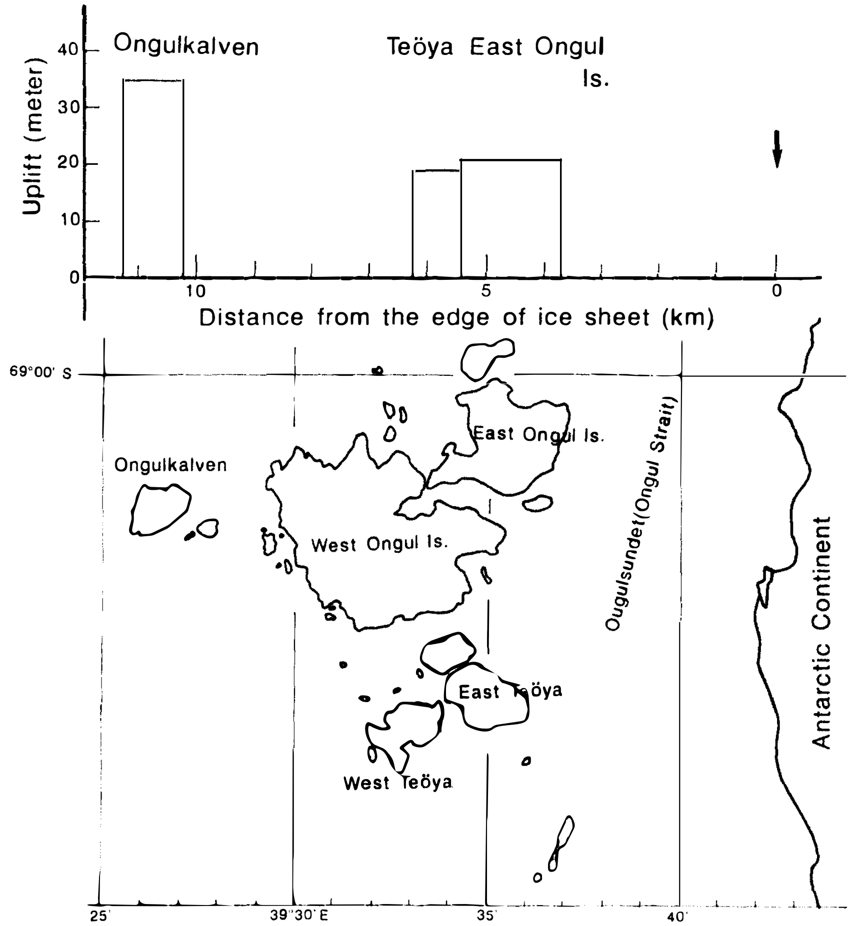


*Fig. 8. The maximum heights of elevated beaches around Syowa Station.*

(KAMINUMA and NAGAO, 1984).

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 areas.

2) The crustal uplift is not a linear phenomenon but a block movement, because the locations of epicenters are in the coastal and offshore areas, 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/ultramicro-earthquakes occur in the coastal area.

5) The crustal uplift continued only 1–2 years during about one decade/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. As the crustal uplift is not a linear movement but an intermittent one, the local earthquakes occur intermittently corresponding with the intermittent crustal uplift.

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