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Local Earthquake Activities around Syowa Station, East Antarctica

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Abstract : Nine local earthquakes of magnitude up to 3.0 were detected by the tripartite seismic network at Syowa Station, East Antarctica during 16 months from June 1987 to September 1988. These earthquakes are located in the coastal area of the Antarctic continent and offshore. As the crustal uplift caused by deglaciation continues at a rate of more than 2.5 mm/y, the local earthquakes seem to be caused by the tectonic stress which is accumulated by the crustal uplift.

1. Introduction

Most seismic stations in Antarctica report a lot of small close events, but most of these can be often identified as the events caused by movements of ice sheet, cracking of ice shelf etc. (Adams, 1969, 1972 ; Browne-Cooper *et al.*, 1967 ; Hatherton and Evison, 1962 ; Kaminuma and Ishida, 1971). For the purpose of determining the locations of micro-earthquakes, which were estimated to occur around Japanese Antarctic Station, Syowa (69°S, 39°E) in East Antarctica, a tripartite seismic network with 1.0 s period seismographs was established at Syowa Station in the winter season of 1973. Only eight local earthquakes were recognized during 10 months (Kaminuma, 1976). S-P times of the earthquakes recorded range from 3 to 24 s, but six earthquakes out of the eight have less than 10 s S-P time. Locations of two earthquakes were determined in Lützow-Holm Bay, one at 20 km WNW and the other at 50 km W of Syowa Station. Estimated by their locations, these earthquakes are identified as tectonic earthquakes. Thereafter no significant local earthquakes were recognized on the seismogram of the routine observation at Syowa Station.

A new large tripartite seismic network of radio-telemetry was established at Syowa Station in 1987 (Kaminuma and Akamatsu, 1987 ; Akamatsu *et al.*, 1988). Some tectonic earthquakes were recorded by the network and are reported in this paper.

2. 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, but the location determined was only for the event of 1952 without its magnitude (Adams *et al.*, 1985). Except this event, 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 operated on the Antarctic continent since the IGY and the occurrence there of small seismic events has been recognized on the seismograms. Hatherton (1961) reported over 300 small earthquakes, up to magnitude 3, recorded at Scott Base (77.9°C, 166.8°E) during the IGY. S-P times of these shocks range from 3 to 38 s, but half of the shocks recorded have S-P times of 4-6 s which correspond to the distances from Mt. Erebus, an active volcano in Antarctica.

Hatherton and Evison (1962) also reported the small local earthquake activities recorded quite frequently at Scott Base and these were attributed to the calving of icebergs from the Ross Ice Shelf. During 1963 and 1964, numerous low-magnitude events, not reported by other stations, were detected at Wilks Station (66.3°S, 110.5°E) (Browne-Cooper *et al.*, 1967). Some of these events seemed to be local earthquakes.

Numerous small earthquakes of magnitude up to 3.5 were recorded at Scott Base and Vanda Station (77.5°S, 161.6°E) in Dry Valleys, Victoria Land between January 1969 and February 1970. Some of the earthquakes were reported as natural earthquakes occurring around the south-eastern part of Victoria Land (Adams, 1969, 1972).

One earthquake (body-wave magnitude 4.3) which occurred on 26 June 1968 was located by Kaminuma and Ishida (1971) on the Antarctic continent, near 20.3°W and 79.9°S. 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

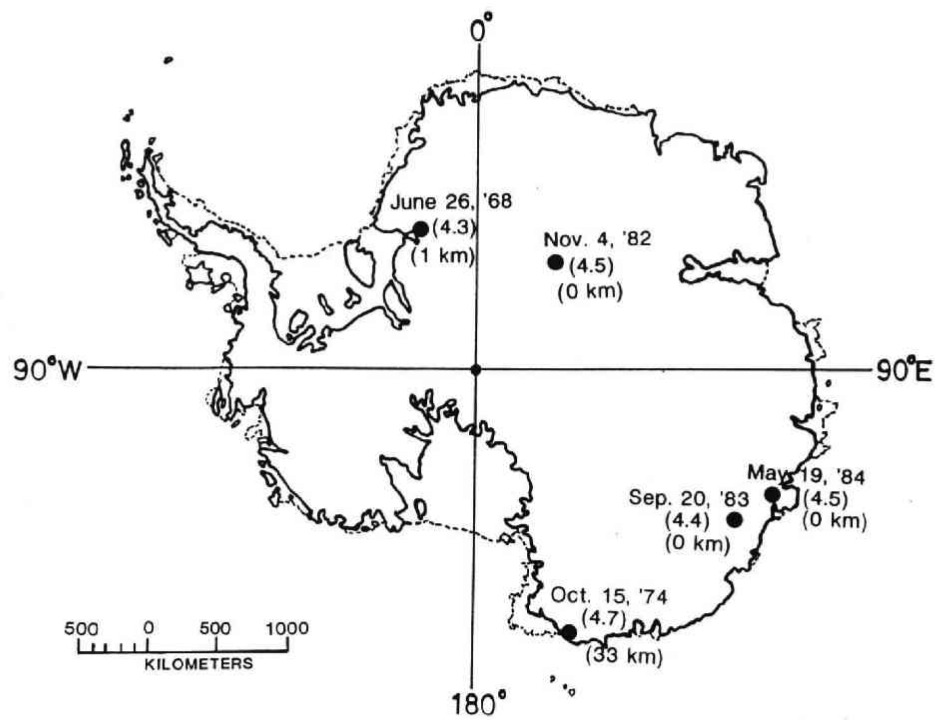


Fig. 1 The earthquake locations in the Antarctic continent with body-wave magnitude and depth.

occurrence in the Antarctic continent determined by the seismic network.

An earthquake near the Oates Land coast (70.5°S, 161.3°E) on 15 October 1974 was the first shock located on the Antarctic continent by the Preliminary Determination of Epicenter Service of the U.S. Geological Survey (PDE of USGS) and by the International Seismological Center (ISC). The earthquake was given body-wave magnitude of 4.9 by USGS and 4.7 by ISC.

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 coast of Queen Maud Land, and 1,100 km east from the location of the 26 June 1986 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 Wilks land, near the coast of the east Antarctic shield area, in 1983 and 1984. The locations of the above five events are given in Fig. 1.

There are very few studies concerning micro-earthquakes in Antarctica. Kaminuma (1976) estimated by the routine seismic observation that the seismicity around Syowa Station in Lützow-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.

3. Seismic Observation Network at Syowa Station

The seismic observation at Syowa Station was started in 1961 with a vertical component short-period seismograph which was installed by the 3rd Japanese Antarctic Research Expedition (JARE-3). 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 observation with the three-component short-period seismograph was continued during the year. In 1967, a three-component long-period seismograph was installed by JARE-8 at Syowa Station 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 at Syowa Station have been published by National Institute of Polar Research, as a series of JARE Data Reports, "Seismological Bulletin in Syowa Station" since 1969.

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 1 March 1970 (Kaminuma and Chiba, 1973). The earthquake detection capability at Syowa Station has been improved by the observation in the new vault.

A tripartite seismic array with three-component seismographs for three sites was established in Syowa Station in 1987 (Kaminuma and Akamatsu, 1987 ; Akamatsu *et al.*, 1988), and the observation by the network has continued until the end of 1989. The main purposes of establishing the seismic network were to study 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.

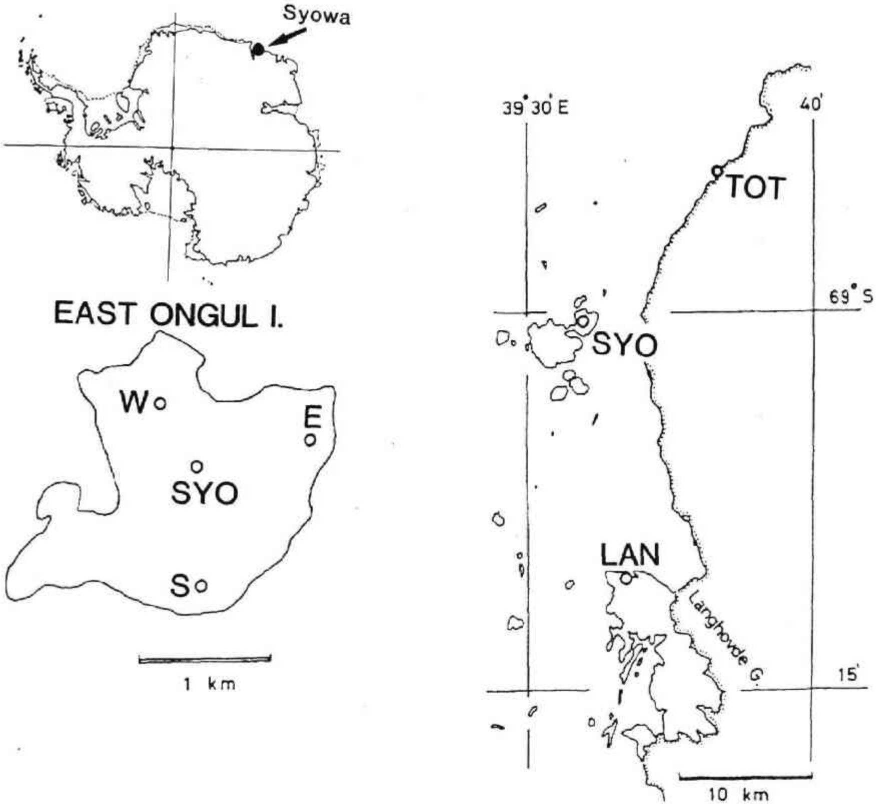


Fig. 2 The tripartite seismic array with three-component seismographs around Syowa Station operated from June 1987 to October 1989. The tripartite array (W, S, E) in East Ongul Island was occupied from February 1988 to December 1989.

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. 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 Fig. 2, were about 1 km. The seismic signals were transmitted by cable wire to the recording system at Earth Science Laboratory (Akamatsu *et al.*, 1989).

4. Seismic Activity

More than 11,400 events were recorded during 16 months from June 1987 to September 1988 (Akamatsu *et al.*, 1989). About 35 percent of the total events were sea-ice shocks, 55 percent were icequakes, 8 percent were teleseisms and 2 percent were the

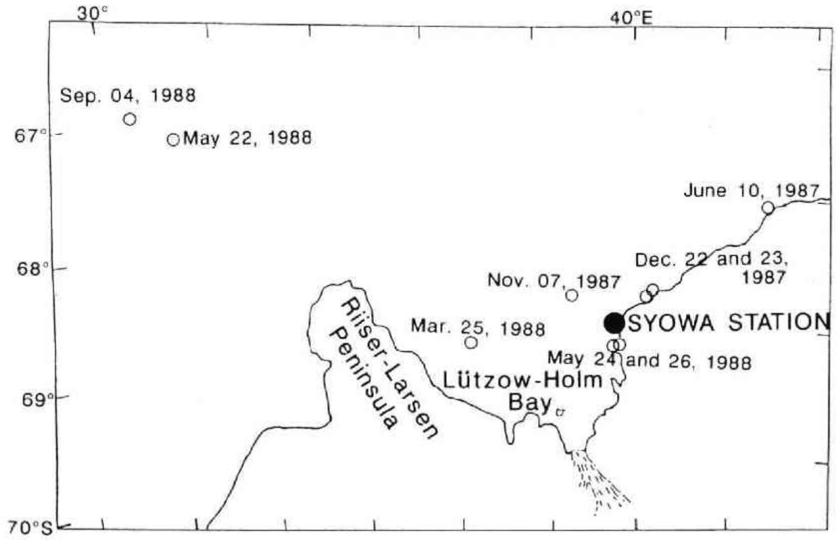


Fig. 3 The locations of local earthquakes around Syowa Station recorded from June 1987 to September 1988.

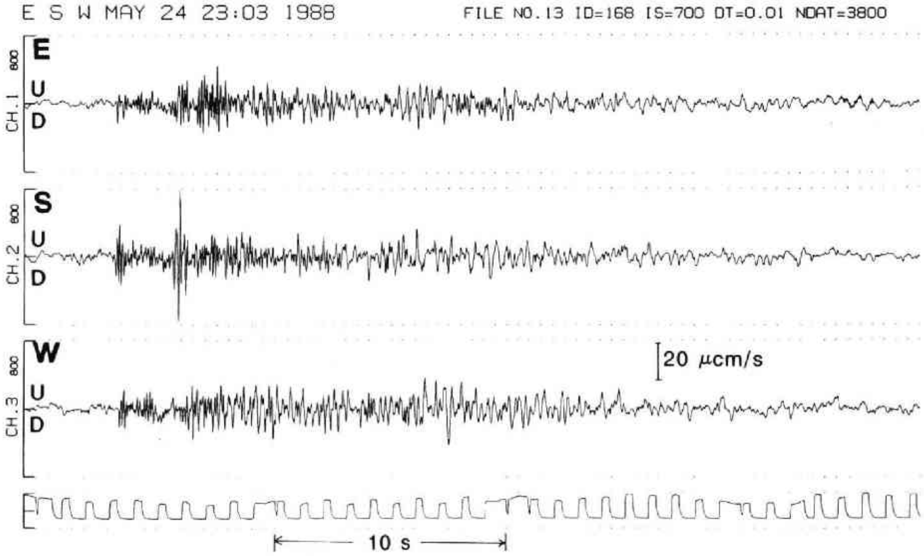
Table 1. List of Local Earthquakes around Syowa Station

Date		Time	Magnitude	Source region
June	10, 1988	1936	2.6	Prince Olav Coast, 170 km NE of SYO
Nov.	07	0623	1.5	Lützow-Holm Bay, 50 km NW of SYO
Dec.	22	1136	1.0	Near Tama Glacier, 50 km NE of SYO
	23	0654	0.9	
Mar.	25, 1989	1516	1.6	Western part of Lützow-Holm Bay, 120 km WNW of SYO
May	22	0258	2.3	N.W. off Riiser-Larsen Peninsula, 350 km NW of SYO
May	24	2303	0.2	The mouth of Langhovde Glacier, 20 km SSE of SYO
	26	2306	−0.8	
Sep.	04	1723	3.0	N.W. of Riiser-Larsen Peninsula, 400 km NW of SYO

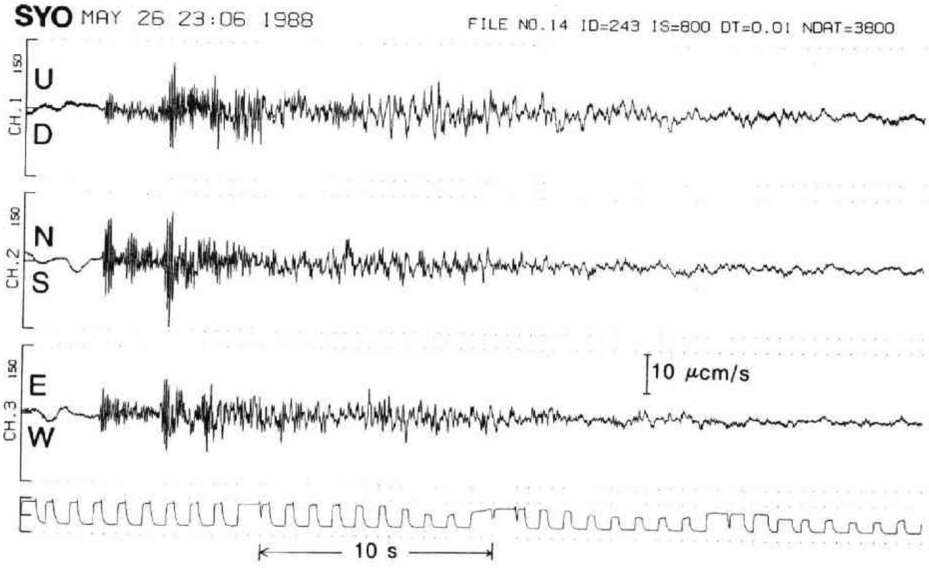
events caused by glacier movements. Only nine local events were detected by the system during the 16 months as listed in Table 1 and shown in Fig. 3.

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 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.

Magnitudes of the two events on May 24 and 26, 1988 located near the Langhovde



(a)



(b)

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.

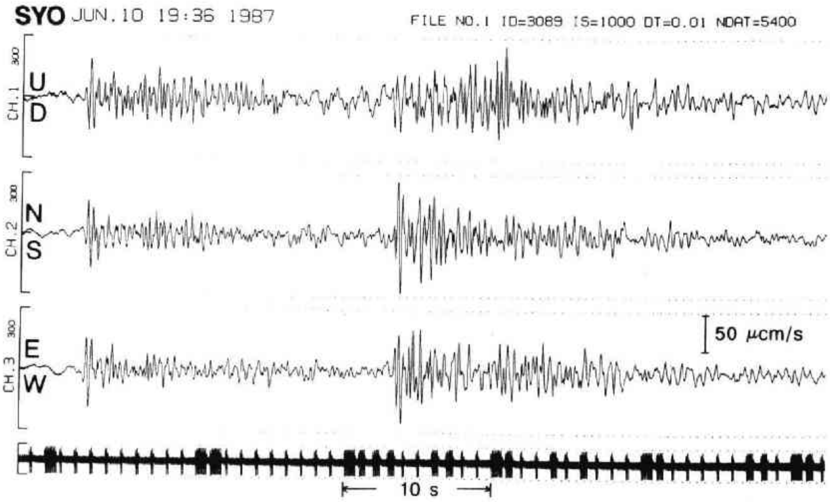


Fig. 5 Three-component seismograms of the event of June 10, 1987 at SYO.

glacier are 0.2 and -0.8, the ultramicro-earthquakes. The seismograms of these two events at SYO are shown in Figs. 4 a and b. As clear phases with amplitude larger than 50 μcm/s are recorded at the distant stations of SYO and TOT, the two events must be not 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 6.5 km/s velocity, 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.

Figure 5 shows the three-component seismograms of the earthquake of June 10, 1987 at SYO, which has about 20 s S-P time and magnitude of 2.6. It must be pointed out strongly that nine events with similar waveforms 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.

Two events of Dec. 22 and 23, 1988 located near the Tottuki Point are almost the same in magnitude, being 1.0 and 0.9. Their waveforms are very similar as shown in Figs. 6 (a) and (b). From the above facts, the two events are probably a double event.

Two events of Nov. 7, 1987 and Mar. 25, 1988 in Lützow-Holm Bay, shown in Fig. 3, seemed similar to the events reported by Kaminuma (1976). The waveforms at SYO of the Nov. 7 event are given in Fig. 7. Two 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.

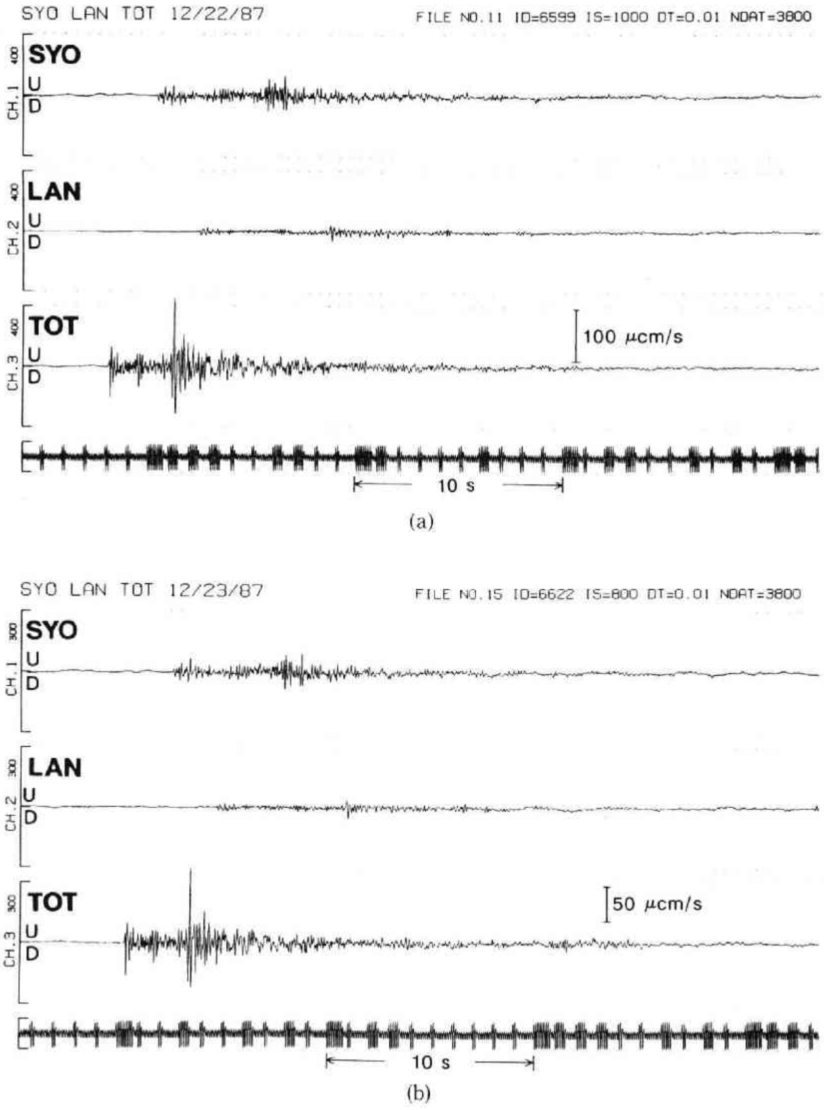


Fig. 6 Vertical component seismograms recorded at SYO, LAN and TOT on December 22, 1987 (a), and on December 23, (b).

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.

5. Discussion

Nine events were detected by the tripartite seismic network at Syowa Station during 16 months from June 1987 to September 1988. Four events out of the nine are located

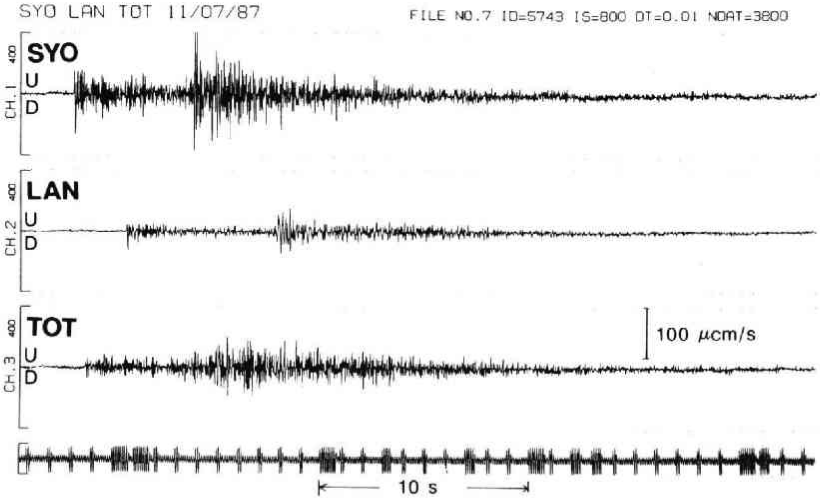


Fig. 7 Vertical component seismograms recorded at SYO, LAN and TOT on November 7, 1987.

offshore, and these are undoubtedly tectonic earthquakes. The other five events located along the coastal area must be also tectonic local earthquakes judging from their waveforms with clear P and S phases recorded at three tripartite sites (Akamatsu *et al.*, 1988, 1989). It is clear that the above nine earthquakes are located only in the coastal area of the continent and offshore.

There are many well-developed elevated beaches and marine terraces in the broad coastal ice-free areas of the Antarctic continent. 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.

Well-developed elevated beaches are found in the coastal ice-free areas around Syowa Station and along the eastern coast of Lützow-Holm Bay. Their maximum heights are 22 m in East Ongul Island, 19 m in Teoya (Island), south of East Ongul Island, and 35 m in Ongulkalven (Island), 5 km west from East Ongul Island. No elevated beaches are found in West Ongul Island.

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/y on the average, possible maximum being 5-6 mm/y (Yoshida and Moriwaki, 1978). The crustal uplift seems to have continued during the last 6,000 years. The local earthquakes mentioned above seem to have been caused by the tectonic stress which was accumulated by the slow-moving crustal uplift after the deglaciation.

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References

Adams, R.D., 1969 : Small earthquakes in Victoria Land, Antarctica, *Nature*, **224**, 255-256.

Adams, R.D., 1972 : Local earthquakes in Victoria Land, in *Antarctic Geology and Geophysics*, 495-499, ed. Adie, R.J., Universitetsforlaget, Oslo.

Adams, R.D., A.A. Hughes and B.M. Zhang, 1985 : A confirmed earthquake in continental Antarctica. *Geophys. J.R. Astr. Soc.*, **81**, 489-492.

Akamatsu, J., S. Yoshikawa and K. Kaminuma, 1988 : Preliminary report of local seismic activity around Syowa Station, East Antarctica, *Proc. NIPR Symp. Antarct. Geosci.*, **2**, 1-6.

Akamatsu, J., N. Ichikawa and K. Kaminuma, 1989 : Seismic observation with local telemetry network around Syowa Station, East Antarctica, *Proc. NIPR Symp. Antarct. Geosci.*, **3**, 1-12.

Browne-Cooper, P.J., G.R. Small and R. Whitworth, 1967 : Probable local seismicity at Wilkes, Antarctica, *N.Z.J. Geol. Geophys.*, **10**, No. 2, 443-445.

Hatherton, T., 1961 : A note on the seismicity of the Ross Sea region, *Geophys. J.R. Astr. Soc.*, **5**, No. 3, 252-253.

Hatherton, T. and F.F. Evison, 1962 : A special mechanism for some Antarctic earthquakes, *N.Z. J. Geol. Geophys.*, **5**, No. 1, 864-873.

Ikami, A., K. Ito, K. Shibuya and K. Kaminuma, 1984 : Deep crustal structure along the profile between Syowa and Mizuho Stations, East Antarctica, *Mem. Natl Inst. Polar Res.*, Ser. C (*Earth Sci.*), **15**, 19-28.

Kaminuma, K. and M. Ishida, 1971 : Earthquake activity in Antarctica, *Antarctic Rec.*, **42**, 53-60.

Kaminuma, K., 1976 : Seismicity in Antarctica, *J. Phys. Earth.*, **24**, 381-395.

Kaminuma, K. and J. Akamatsu, 1987 : Nankyoku Syowa Kiti Fukin no Zishin (Local earthquakes around Syowa Station, Antarctica), *Nankyoku Shiryo* (*Antarctic Rec.*), **31**, 177-185.

Kaminuma, K. and H. Chiba, 1973 : Syowa Kiti no Shin-Zishinkeishitsu to Zishin-Kenchiritsu (The new seismographic vault and the detection capability of Syowa Station, Antarctica), *Nankyoku Shiryo* (*Antarctic Rec.*), **46**, 67-82.

Kaminuma, K., T. Eto and M. Yoshida, 1968 : Syowa Kiti no Zishin Kansoku (Seismological observation at Syowa Station, Antarctica), *Nankyoku Shiryo* (*Antarctic Rec.*), **33**, 65-70.

Omoto, K., 1977 : Geomorphic development of the Soya Coast, East Antarctica-Chronological interpretation of raised beaches based on levellings and radiocarbon datings, *Sci. Rep. Tohoku Univ., Ser. 7* (*Geogr.*), **27**, 95-148.

Watanabe, H., 1971 : Kinchi Zishin no Magunichudo (Determination of earthquake magnitude at regional distance in and near Japan). *Zisin* (*J. Seis. Soc. Jpn.*), *2nd ser.*, **24**, 189-200.

Yoshida, Y. and K. Moriwaki, 1979 : Some consideration on elevated coastal features and their dates around Syowa Station, Antarctica, *Mem. Natl Inst. Polar Res., Spec. Issue*, **13**, 220-226.