Proc. NIPR Symp. Antarct. Geosci., 4, 90–99, 1990

SEISMIC OBSERVATION WITH LOCAL TELEMETRY NETWORK AROUND SYOWA STATION, EAST ANTARCTICA (2)

Junpei AKAMATSU[1], Nobuo ICHIKAWA[1] and Katsutada KAMINUMA[2]

[1]*Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji 611*
[2]*National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: A local telemetry seismic network was established around Syowa Station to study local seismicity and wave characteristics in the Lützow-Holm Bay region, East Antarctica. More than 14000 events were recorded during the period from June 1987 through January 1989. Most of them were icequakes, though 1043 teleseisms and 9 local earthquakes were identified.

Local earthquakes of magnitude ranging from −1 to 3 occurred in the coastal and offshore regions of the continent. In the observational period, no earthquakes with M larger than 2 seemed to occur within 500 km under the continent. The locations of local earthquakes were discussed in relation to possible faults inferred from surface geology and submarine topography. Apparent phase velocities were examined to discuss the velocity structures and source depths.

Locations of iceshocks of sea ice were examined to confirm the velocity model. It was clarified that iceshocks occurred mainly in the boundary area between the multi-year ice and the first-year ice.

1. Introduction

Seismic observation with local radio telemetry network was started by the 28th Japanese Antarctic Research Expedition (1986–1988) (JARE-28), from June 1987 along the Sôya Coast. The main objective of the observation is to study the wave characteristics and seismicity in relation to regional tectonics of the Lüzow-Holm Bay region, East Antarctica. More than 3400 events were observed from June 1987 through January 1988 by JARE-28, and discussed in the previous paper, together with description of network design (AKAMATSU *et al.*, 1989). In addition, a small tripartite array was installed by JARE-29 (1987–1989) in January 1988 around Syowa Station to examine the wave field in and around East Ongul Island. During the period from February 1988 through January 1989, nearly 10000 events were recorded, among which 5 local micro- and ultramicro-earthquakes were included. To study the velocity structure, we examined the phase velocities of local earthquakes and located the ice-shocks occurring around East Ongul Island.

2. Observation and Records

Figure 1 shows the location of the seismic network. The larger network consists of three sites with a three-component 1-s seismometer; Syowa Station in East Ongul Island (SYO), Tottuki Point (TOT) and Langhovde (LAN). TOT and LAN are

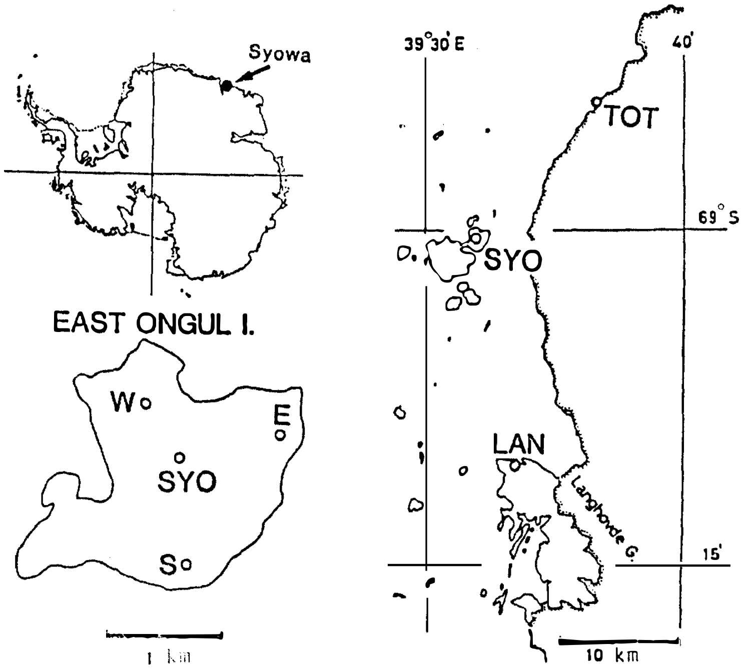

Fig. 1. Location of seismic network around Syowa Station.

installed on the continental outcrops, located 15 and 20 km from SYO, respectively along the Sôya Coast. The small tripartite array consists of 1-s vertical seismometers. Array dimension is about 1.5 km. TOT and LAN are supported by solar battery and linked by radiotelemetry to the recording system. The other sites, SYO and tripartite array (E, S, W), are linked directly to the system. Detailed explanations of the network and system are given in the previous paper (AKAMATSU *et al.*, 1989).

During the observation period of JARE-29, radiotelemeter site LAN did not operate from May 24 to August 1 because of power stoppage of solar battery in the winter season; TOT also from July 19 to July 27. The other sites operated all through the year.

Table 1 lists the amplitude distribution of events, whch were divided into five

Table 1. Classification of events and frequency distribution of amplitude at SYO (February 1, 1988–January 31, 1989).

Max. Amplitude (μ cm/s)	>200	200–100	100–50	50–25	<25	Total
Sea iceshock	301	356	425	362	761	2225
Icequake	8	31	114	247	6631	7031
Glacier movement	0	2	16	12	10	40
Teleseism	14	25	55	102	346	542
Local earthquake	0	0	1	3	1	5
Total	323	414	611	726	7769	9843

Ground noise	Electric noise	Test	Total
261	38	382	681

groups: local earthquake, teleseism, iceshock of sea ice around the Ongul Islands, shock-type icequake in continental thick ice sheet and continuous vibration caused by glacier movement, with visual analysis of wave forms. For the sake of easy searching of data, index data files are compiled on a magnetic drum, in which identification number, date, time, group, amplitudes of three sites (SYO, LAN and TOT) and necessary comments are written.

3. Local Earthquakes

Examples of sesmograms for local earthquakes are shown in Fig. 2. Figure 3 shows the epicenter locations together with those observed in 1987. Table 2 lists the event parameters.

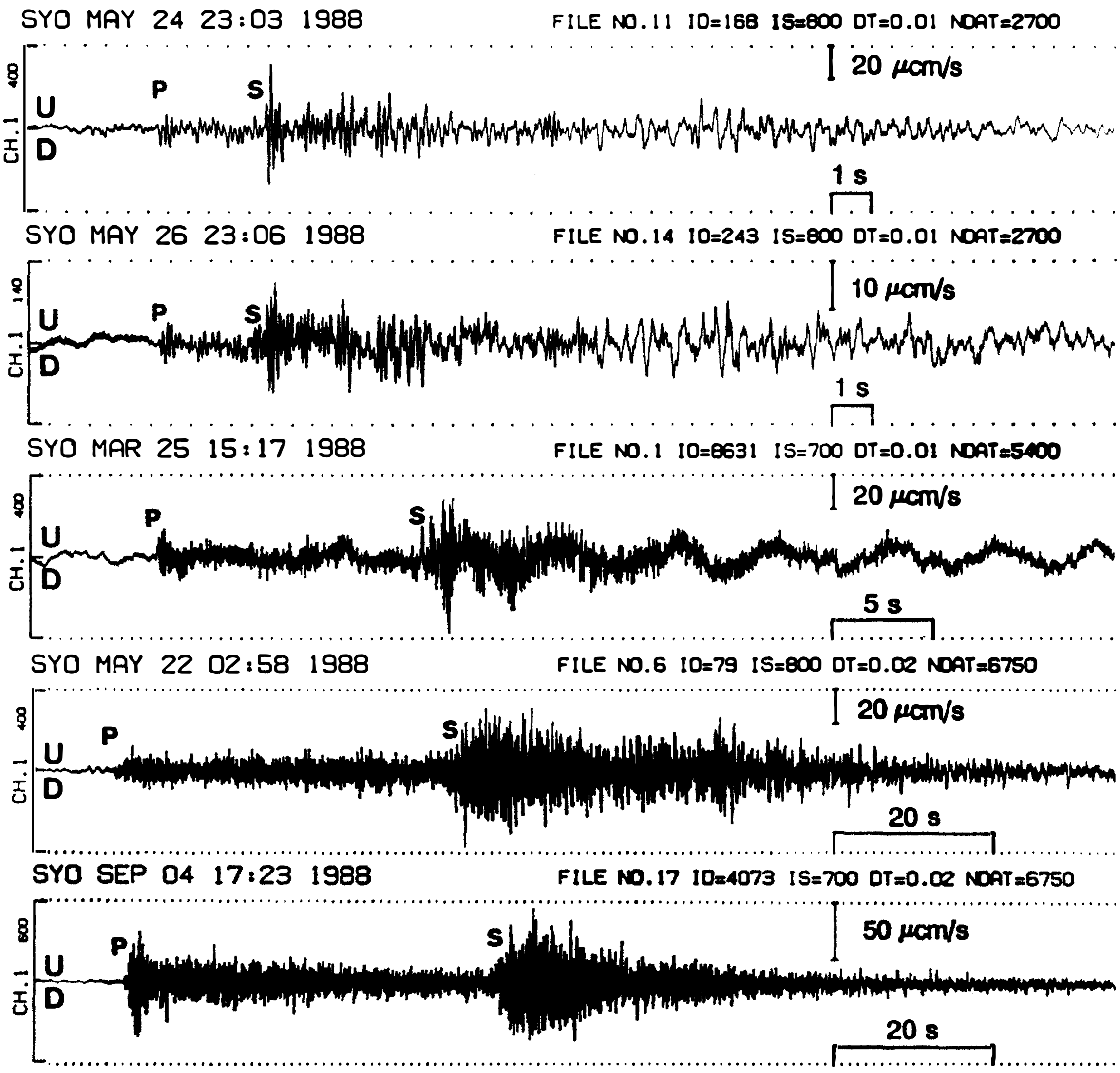

Fig. 2. Seismograms of local earthquakes at SYO (vertical components) observed from February 1989 through January 1989 (JARE-29).

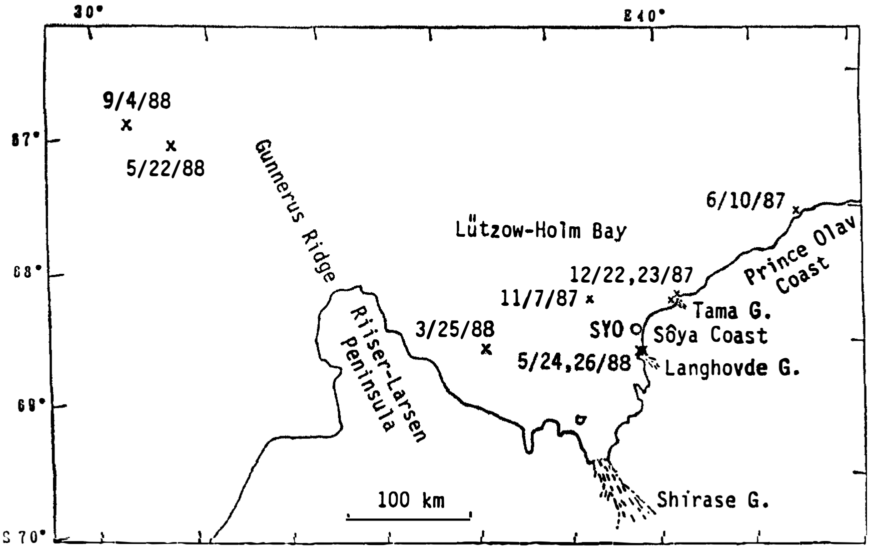

Fig. 3. Epicenter locations of local earthquakes (×) *around Syowa Station* (○).

Table 2. List of local earthquakes around Syowa Station (from June 1987 through January 1989).

ID NO.	Date	Time	M	AZM[1)]	V[2)] (km/s)	Region
3089	87.06.10	1936	2.6			Prince Olav Coast, 170 km NE of Syowa Station[3)]
5743	87.11.07	0623	1.5			Eastern part of Lützow-Holm Bay 50 km NW of Syowa Station
6599	87.12.22	1136	1.0			Mouth of Tama Glacier 50 km NE of Syowa Station
6622	87.12.23	0654	0.9			Mouth of Tama Glacier
8631	88.03.25	1516	1.6	259	7.017±0.113	Western part of Lützow-Holm Bay 120 km W of Syowa Station
10079	88.05.22	0258	2.3	289	9.282±0.396	NW off Riiser-Larsen Peninsula
10168	88.05.24	2303	0.2	166	6.993±0.466	Mouth of Langhovde Glacier 20 km S of Syowa Station
10243	88.05.26	2303	−0.8			Mouth of Langhovde Glacier 20 km S of Syowa Station
14073	88.09.04	1723	3.0	291	9.812±0.416	NW off Riiser-Larsen Peninsula

1), 2) Azimuth, AZM, and phase velocity, V, of initial phase were determined with small array in East Ongul Island.

3) Nine other events occurring in the region were observed during the preliminary observation from March to April in 1987.

Local magnitude is estimated with the formula for shallow event (Watanabe, 1971; Maeda, 1984),

$$M = 1.18 \log (A_{v\,max}) + 2.04 \log R - 4.48, \qquad (1)$$

where $A_{v\,max}$ is maximum velocity amplitude in μ cm/s and R is focal distance in km. R is estimated with S-P time, assuming $V_p/V_s = \sqrt{3}$ and the velocity model determined by the explosion experiment (Ikami *et al.*, 1984).

Source azimuth, *AZM*, and phase velocity, *V*, in Table 2 were determined with 4 sites in East Ongul Island using several peaks and troughs of initial phase.

Ultramicro-events occurred in the same places near the mouth of the Langhovde Glacier (10168, 10243). Unfortunately, the nearest site, LAN, was not available as mentioned already. However, we can discuss the source depths as follows; V_p of the surface layer with thickness of 4 km is estimated as 6.0 km/s and V_p of the second layer with thickness of 20 km, as 6.3 km/s (IKAMI *et al.*, 1984). Estimated phase velocity of 6.99 km/s corresponds to emergent angle of 25° in the second layer, which gives source depth of about 10 km.

The phase velocity, 6.99 km/s, of the events is close to the apparent velocity of explosion, 6.95 km/s, which is used for P^* (IKAMI *et al.*, 1984). Taking account of the short focal distances, it is considered that the Conrad is shallower in the coastal region than that of the Mizuho Plateau (30 km deep) on the continent where the explosion experiment was carried out.

There possibly exists a typical geological structure such as a fault along an active glacier (AKAMATSU *et al.*, 1989). Occurrences of these events appear to support the idea.

We observed 3 other events in the Lützow-Holm Bay and off Riiser-Larsen Peninsula regions. The estimated phase velocity for the event on the Bay is 7.02 km/s, nearly the same as the P^* value. Thus, the source depth is considered to be shallow.

Two distant events, off the Riiser-Larsen Peninsula, are very interesting, because they occurred in the Gunnerus Ridge region. It is pointed out that there exists a geological structure extending from the mouth of the Shirase Glacier to the eastern margin of the Gunnerus Ridge ascertained by submarine topography (MORIWAKI, 1979).

Another interesting evidence is an extremely small attenuation of waves. These two events have a considerably long coda duration with high frequency contents (Fig. 2) in spite of small magnitudes, showing a very small attenuation of both intrinsic absorption and scattering loss due to heterogeneities in relation to the stable tectonics in the region (AKAMATSU, 1990, 1991).

4. Iceshocks around East Ongul Island

A lot of iceshocks were observed throughout the observation period (Table 1). In order to obtain the information about velocities in and around the Ongul Islands and to check the capability of utilizing the small array, we examined the source locations of sea-ice shocks.

Figure 4 shows an example of seismograms. Typical features are; grazing incidence of initial *P* phase and extremely large excitation of Rayleigh wave. The situation resembles Lamb's problem, because sea-ice shock is a typical surface event on a half space without layering. The linear dimension of East Ongul Island is less than about 2.5 km, which is much smaller than the thickness of 4 km for the surface layer with V_p = 6 km/s (ITO and IKAMI, 1984; IKAMI *et al.*, 1984; ITO *et al.*, 1984). Therefore, the velocity structure can be considered as a half space for iceshocks occurring around the islands.

The locations were determined with *P*-onset time, t_p, and *S-P* time, t_{s-p}, where

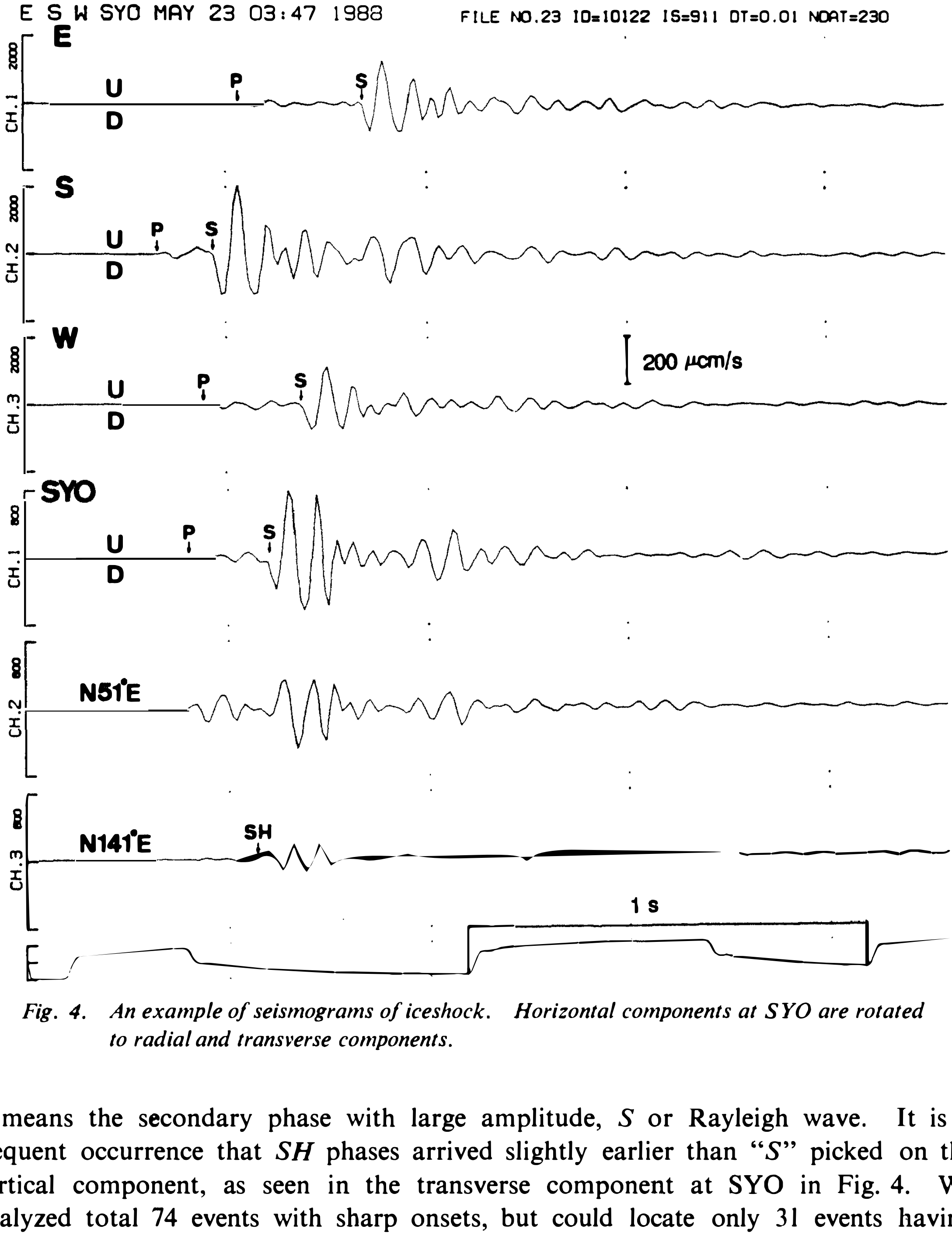

Fig. 4. An example of seismograms of iceshock. Horizontal components at SYO are rotated to radial and transverse components.

S means the secondary phase with large amplitude, S or Rayleigh wave. It is a frequent occurrence that SH phases arrived slightly earlier than "S" picked on the vertical component, as seen in the transverse component at SYO in Fig. 4. We analyzed total 74 events with sharp onsets, but could locate only 31 events having linear relations between t_p and t_{s-p}. Figure 5 shows examples of the relations with variuos V_p/V_s. Table 3 lists the distribution of V_p/V_s thus obtained. Mean of V_p/V_s is 1.82 ± 0.10, a little larger than Poisson's relation. V_p/V_{Rayleigh} is reported at 1.95 from the explosion experiment in East Ongul Island (ITO *et al.*, 1984). Thus, there is an uncertainty in picking the "S", S or Rayleigh wave. However, for rough approximation, we determined origin time, t_o, with each linear t_p *versus* t_{s-p} plot, assuming that we read the same wave group on all sites for each event. Figure 6 shows the epicenter locations determined with t_{p-o} thus obtained and V_p of 6.0 km/s.

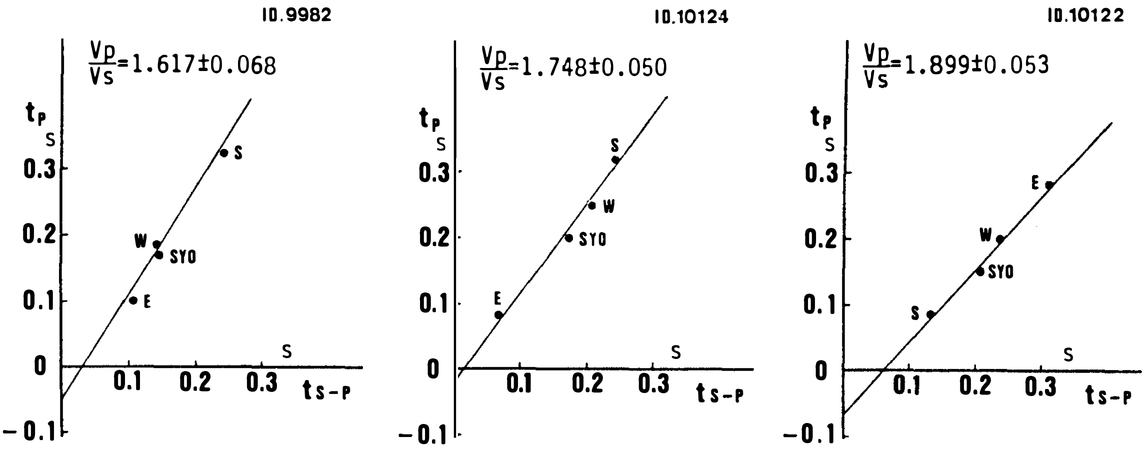

Fig. 5. Examples of the relations between t_p and t_{s-p} for iceshocks around East Ongul Island.

Table 3. Frequency distribution of V_p/V_s for iceshocks around East Ongul Island.

V_p/V_s		N
$< 0.95\sqrt{3}$	(< 1.645)	1
$0.95\sqrt{3} - \sqrt{3}$	($1.645 - 1.732$)	3
$\sqrt{3} - 1.05\sqrt{3}$	($1.732 - 1.819$)	13
$1.05\sqrt{3} - 1.10\sqrt{3}$	($1.819 - 1.905$)	9
$1.10\sqrt{3} - 1.15\sqrt{3}$	($1.905 - 1.992$)	3
$> 1.15\sqrt{3}$	(> 1.992)	2
Total		31

It is very interesting that iceshocks occurred mainly in two regions; one from Miharasi Peak, NE of East Ongul Island, to Iwa-zima Island located 1.5 km NNE of the Peak; and the other in the small channel between East and West Ongul Island. These regions are characterized with disordered brash ice and hummock ice with many icebergs stranded, located on the boundary between the multi-year ice around the Ongul Islands and the first-year ice in the Ongul Strait (MORIWAKI, 1979).

It has been usually observed that icequakes are triggered very frequently around the islands by blizzard. And we had supposed that icequakes occur along the tidal cracks of sea ice along the coastal line from the preliminary observation and analysis (AKAMATSU *et al.*, 1989). However, our result is quite different. In our opinion, icebergs aground play an important role for generation and propagation of seismic waves. The directions of wave propagations observed during the period from April 1976 through January 1977 (KAMINUMA and HANEDA, 1979) seem consistent with our results. In our analysis, however, we dealt with only large events having sharp onset and linear relation between t_p and t_{s-p}. More detailed analysis should be carried out. Anyway, the obtained location seems reasonable judging from topography of the islands and situation of sea ice, and thereby we are convinced that our network can be used for detailed study of wave field.

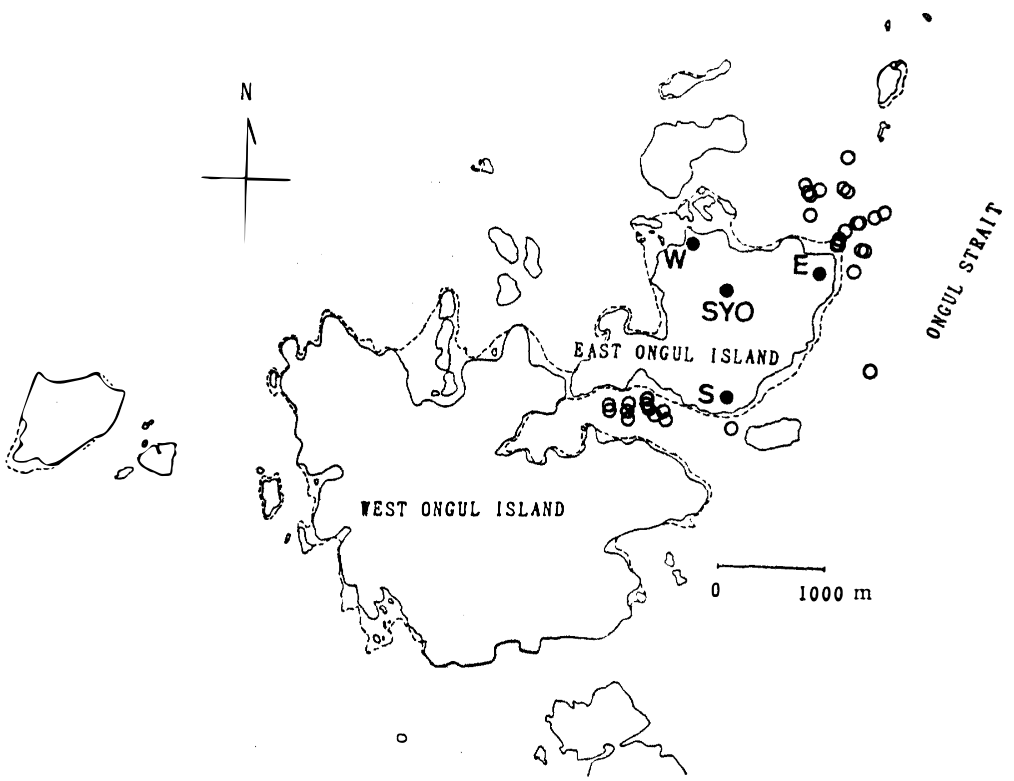

Fig. 6. Epicenter locations of iceshocks around East Ongul Island.

5. Discussion and Future Problems

During the observational period of JARE-28 including the preliminary observation, several local earthquakes occurred in relation to geological structure in the Lützow-Holm Bay region (AKAMATSU *et al.*, 1989). That is, the source locations were; (1) the coastal region of the Prince Olav Coast near the boundary between the Lützow-Holm Complex and the Rayner Complex (February–March and June 10, 1987); (2) northern extension of the glacial trough on the sea floor of Lützow-Holm Bay (November 7, 1987): (3) the mouth region of the Tama Glacier (December 22 and 23, 1987).

In the period of subsequent JARE-29, 5 local earthquakes were observed. (1) Two events (May 24 and 26, 1988) occurred at the mouth of the Langhovde Glacier, from which deep glacier troughs extend. The Ongul Strait is one of the branches of the troughs. (2) Although the uncertainty of locations is rather large, two events (May 22 and September 4, 1988) occurred near the Gunnerus Ridge, a northern extension of the Riiser-Larsen Peninsula. There is a large difference in topography between the eastern and western regions of Lützow-Holm Bay divided by the geological structure from the Shirase Glacier to the eastern margin of the Gunnerus Ridge (MORIWAKI, 1979, 1986). (3) An event (March 25, 1988) occurred in the western region of the Bay, but a detailed submarine topography is not clarified.

Considering the sensitivity of the observational system, we can detect local events with $M>2$ occurring within 500 km. However, all source locations were limited to the coastal and offshore areas of the continent. No earthquakes seem to occur under the continent in the observational period. The distribution of source locations is very interesting in relation to tectonics of the region. For further details, we should utilize the seismic observation carried out routinely at Syowa Station (SHIBUYA, 1986). It became clear that the local telemetry network was very useful to discriminate local earthquakes from icequakes occurring very frequently around the station. Therefore, the seismograms of the routine seismic observation system for the local events thus discriminated can be good examples for monitoring local seismicity.

The phase velocities for local earthquakes estimated with the small array in the island are consistent with the velocity model inferred from the explosion seismology. However, it is reasonable to consider that the depths of the Conrad and the Moho are shallower than those of the model for the continent as mentioned in the previous section. We will discuss the detailed structure with combined analysis for larger and smaller array data of teleseism as well as local events.

6. Conclusion

A local telemetry seismic network was installed along the Sôya Coast around Syowa Station to study the local seismicity and the characteristics of wave fields in the Lützow-Holm Bay region. More than 14000 events were recorded during the period from June 1987 through January 1989. Nine local shallow earthquakes were located in the coastal and offshore areas of the continent, and discussed in relation to possible fautls and geological structures inferred from surface geology and submarine topography. No local earthquakes were detected under the continent.

The phase velocities for local events estimated with the small array in East Ongul Island were consistent with the results of explosion experiments, although suggesting shallower crustal boundaries than the continental model.

The epicentral distribution of iceshocks obtained with the small array was considered reasonable from the situation of sea ice, iceberg aground and topography around the islands. This also shows the availability of the network to study wave field around the islands and in the Lützow-Holm Bay region.

The seismic observation with the telemetry network was carried out through October 1990 by JARE-30.

Acknowledgments

The authors express their sincere thanks to Prof. Y. OHYAMA, leader of the wintering party of JARE-28, Prof. O. WATANABE, leader of JARE-29, Prof. T. HOSHIAI, leader of JARE-28 and Prof. K. SHIBUYA of National Institute of Polar Research for their encouragement for this study. The authors express their hearty thanks to all the members of JARE-28 and JARE-29 for their efforts in carrying out the observation.

References

AKAMATSU, J. (1990): Heterogeneity of lithosphere in the Lützow-Holm Bay region, East Antarctica (abstract). Proc. NIPR Symp. Antarct. Geosci., **4**, 243.

AKAMATSU, J. (1991): Coda attenuation in the Lützow-Holm Bay region, East Antarctica. PEPI, Special Issue on "Scattering and Attenuation of Seismic Waves" as Proc. Sym. S-13, 25th, Gen. Meeting of IASPEI (in press).

AKAMATSU, J., ICHIKAWA, N. and KAMINUMA, K. (1989): Seismic observation with local telemetry network around Syowa Station, East Antarctica. Proc. NIPR Symp. Antarct. Geosci., **3**, 1–12.

IKAMI, A., ITO, K., SHIBUYA, K. and KAMINUMA, K. (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.

ITO, K. and IKAMI, A. (1984): Upper crustal structure of the Prince Olav Coast, East Antarctica. Mem. Natl Inst. Polar Res., Ser. C (Earth Sci.), **15**, 13–18.

ITO, K., IKAMI, A., SHIBUYA, K. and KAMINUMA, K. (1984): Upper crustal structure beneath the Ongul Islands, East Antarctica. Mem. Natl Inst Inst. Polar Res., Ser. C (Earth Sci.), **15**, 3–12.

KAMINUMA, K. and HANEDA, T. (1979): Nankyoku Syowa Kiti de kansoku sareta hyôshin (Icequakes around Syowa Station, Antarctica). Nankyoku Shiryô (Antarct. Rec.), **65**, 135–148.

MAEDA, N. (1984): Magunichûdo no kettei seido ni tsuite (On accuracy of magnitude determination). Zisin (J. Seismol. Soc. Jpn.), 2nd Ser., **37**, 310–313.

MORIWAKI, K. (1979): Submarine topography of the central part of Lützow-Holm Bay and around Ongul Islands, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **14**, 194–209.

MORIWAKI, K. (1986): Tairikudana no chikei (Topography of continental shelf). Nankyoku no Kagaku, 5. Chigaku (Science of Antarctica, 5. Earth Sciences), ed. by Natl Inst. Polar Res. Tokyo, Kokon Shoin, 181–192.

SHIBUYA, K. (1986): Syowa Kiti no jinsin kansoku (Seismic observation at Syowa Station). Nankyoku no Kagaku, 5. Chigaku (Science in Antarctica, 5. Earth Sciences), ed. by Natl Inst. Polar Res. Tokyo, Kokon Shoin, 279–285.

WATANABE, H. (1971): Kinchi jishin no magunichûdo (Determination of earthquake magnitude at regional distance in and around Japan). Zisin (J. Seismol. Soc. Jpn.), 2nd Ser., **24**, 189-200.

(Received February 28, 1990; Revised manuscript received May 8, 1990)