Korean Journal of Polar Research 10(2): 103-107
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Local Seismicity and Crustal Uplift around Syowa Station, Antarctica

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ABSTRACT. Seismic observations at Syowa Station (69°S, 39°E) were stared in 1959. Phase readings of earthquakes have been published by National Institute of Polar Research once a year since 1968, as one of the Data Report Series. Ten local earthquakes were detected on short period seismograms at Syowa Station in 1990-1997. The seismicity during the period from 1990 to 1997 was lower than that from 1987 to 1989 when epicenters of local earthquakes were determined by a tripartite seismic array. The seismic array was operated during only three years in 1987-89.
The Antarctic coastal area and surrounding islands including Syowa Station are places where crustal uplift has occurred after deglaciation. A dynamics of the crustal uplift around Syowa Station has been discussed using geomophological, oceanic tide, seismic and leveling data, and the crustal uplift is estimated to be an intermittent phenomenon. When local seismic activity is high, the crustal uplift is estimated to be going on. On the contrary, the crustal uplift is in dormancy when the local seismicity is low.

Key Words: seismicity, crustal uplift, deglaciation, intermittent phenomenon

Introduction

The Antarctic continent was well-known as an aseismic continent by the International Geophysical Year (IGY) in 1957~1958. According to the establishments of seismic stations in the Antarcitc, some earthquakes became to be located in the Antarctic continent, even though the seismicity is very low.

Kaminuma *et al.* (1998) summarized the local earthquake activity around Syowa Station (69°S, 39°E), which is located on East Ongul Island in Lützow-Holm Bay, East Antarctica. Nine local earthquakes were detected from wave forms on short period seismograms at Syowa Station in 1990-1996. Another one local event was detected in 1997. The local seismicity in 1990-1997 was very low to comparing with that in 1987-1989 when local earthquake locations were determined by a tripartite seismic array (Akamatsu *et al.* 1988, 1989; Kaminuma and Akamatsu 1992).

The Antarctic coastal area and surrounding islands are places where the crustal uplift has occurred after deglaciation. Characterization of crustal movement and estimation of sea level change have been accomplished using a variety of classical high precision methods at Syowa Station. Kaminuma (1996) summarized a process of the crustal uplift.

To detect the crustal movement around Syowa Station, a leveling survey route was established on East Ongul Island in 1982, and repeated measurements over the route were made in 1992, 1996 and 1997. However there was no significant height change of leveling at Syowa Station during 14 years in 1982-1996 (Kaminuma and Kimura 1997).

In this paper, a dynamics of the crustal uplift around Syowa Station is discussed using the seismic oceanic tide, geomophological and leveling data.

Local Earthquakes

No large earthquakes of magnitude greater than 5

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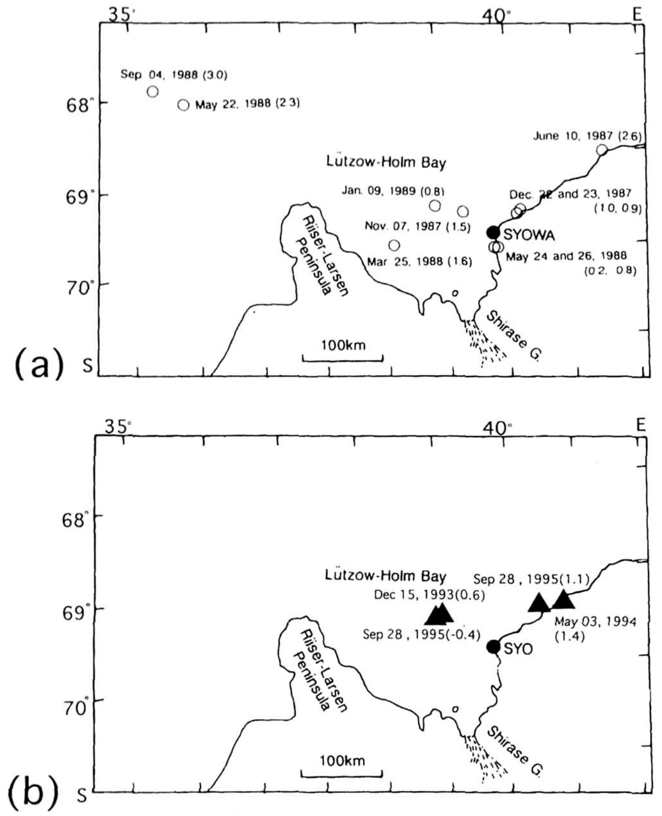

Fig. 1. Local earthquake locations around Syowa Station with magnitude written in the parenthesis. The earthquakes shown with open circles in 1987-89 were located by a seismic array (upper) and those with solid triangles in 1990-96 were determined from a single station (lower).

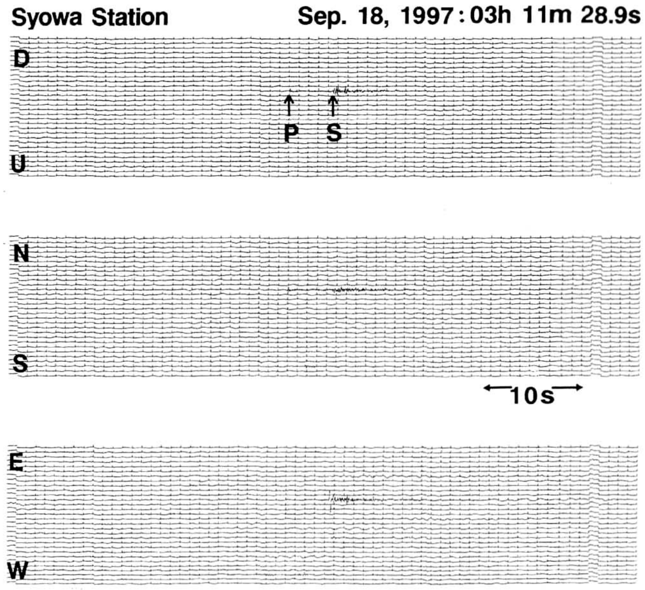

Fig. 2. Three-compornent short period seismogram at Syowa Station for a local event on Sep. 18, 1997.

have been located in the Antarctic continent; earthquake activities with smaller magnitude have only detected by the worldwide seismic network and local earthquakes are observed by some local seismic networks in the Antarctic. The tripartite seismic array had been operated at Syowa Station in 1987-1989 for studying the local seismicity and crustal structure. Ten local earthquakes were located by the tripartite array during the 29 months from June 1987 to October 1989 as shown in Fig. 1 (a) (Akamatsu *et al.* 1988, 1989).

Attempts were made to locate earthquake epicenters of the local events using the first particle motion of the initial phase and P-S time of wave forms at a single station since 1990 (Kaminuma *et al.* 1998). Nine local events were detected on short period seismograms at Syowa Station. The P-S time of the nine events ranged from 3.7s to 16.2s. Four events out of the nine were located using the first particle motion of the initial phase and P-S time of Syowa Station as shown in Fig. 1 (b). It is clear in Fig.1 that the four local events were located in the area where local earthquakes had been located in 1987-1989.

One local event was also detected on short period seismograms in 1997. The three-component seismogram of the event is shown in Fig. 2. The initial phase (P phase) arrived Syowa Station at 03h 11m 28.9s (UT) on Sep. 18. The event has 4.5 s in P-S time and 0.1 in magnitude. One of authors (Kanao) wintered at Syowa Station in 1997 and scaled all seismograms through the wintering season carefully. However no other local events were detected.

Figure 3 shows the annual number of local earthquakes in the vicinity of Syowa Station detected on the routine observation seismograms of three-component short period seismographs. The arrows indicate that the actual number of earthquakes is more than that in the figure because the observation periods of those terms were less than 12 months. The seismicity in 1997 had continued the state of low activity. Therefore ten local earthquakes were detected at Syowa Station during eight years in 1990-1997, however the seismicity was very low compared with that occurred during the previous three years in 1987-1989.

A process for the local earthquake activity in the vicinity of Syowa Station was suggested by

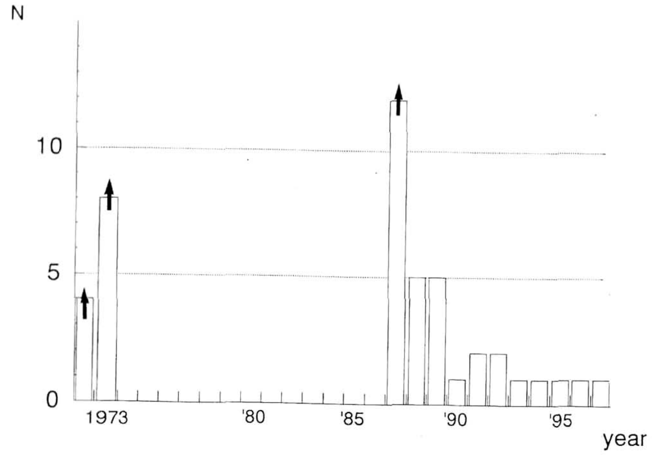

Fig. 3. Annual frequency of local earthquakes observed at Syowa Station. Y-axis indicates the number of earthquakes. Arrows show the possibility that the exact number is larger than that shown in the figure.

Kaminuma and Akamatsu (1992) as follows:

1) Local earthquakes around Syowa Station are inferred to be caused by the tectonic stress which is accumulated by the crustal uplift after deglaciation, as the earthquakes are located in the coastal and offshore areas.

2) The rate of stress accumulation is very small, so that only small, micro/ultra-micro earthquakes of which magnitude less than 3 occur in the coastal and offshore areas.

3) The crustal uplift occurs only for a few years during one decade/more. The occurrence of earthquakes corresponds with the intermittent crustal uplift (see Fig. 3).

Sea Level Change

Syowa Station is the only station in the coastal area of the Antarctic continent where tidal observations have been continued more than 30 years; normally observations are disturbed by sea ice and tide gauges are not installed at the most of the coastal stations in the Antarctic. The observation of the oceanic tide at Syowa Station also had many troubles up to the end of the 1970's. A new tide gauge was installed at Syowa Station in 1981. The new one uses a strain gauge sensor. The mean sea level has been monitored continuously since that time and monthly mean sea level became to be available throughout the year.

A trend in sea level falling at a rate of 9.5 mm/y was obtained by Odamaki *et al.* (1991) using the data collected in 1981-1987. Considering the rise of global mean sea level at the rate of 1~2 mm/y, the falling rate of mean sea level at Syowa Station should be over 10 mm/y.

Michida *et al.* (1995) estimated the mean sea level change at Syowa Station using the data collected during 18 years in 1957-1992. They obtained a trend of sea level falling at a rate of 4.5 mm/y.

Crustal Uplift

Elevated beaches and the emergent marine deposits represent important clues for estimating vertical crustal movement, sea level change, ice advance and retreat, and hence environmental change in the polar regions. Evidence of past glaciation is observed around Syowa Station : Erratic boulders, glacial scour and various glacial deposits etc. can be found in the snow free area. Shell fossils have been found on the elevated beaches around Syowa Station and the date of the fossils was determined to be 5000~6000 BP. Many elevated beaches and marine terraces are recognized around Syowa Station. The maximum height of the elevated beaches is about 20 m. The uplift rate of the elevated beaches is estimated to be 3~6 mm/y from the geomophological data.

There is a discrepancy in the crustal uplift rate between the 10 mm/y falling (crustal uplift) of sea level and 3-6 mm/y uplift of the elevated beaches. The uplift rate of the elevated beaches with a rate of 3-6 mm/y is the mean value during the last 5000-6000 years, while the rate of sea level falling from tide gauge data is averaged over several years. If the crustal uplift occurs intermittently, the rate of the uplift can be larger than 3-6 mm/y as presented by the geomophological data and sea level falling rate by Michida *et al.* (1995). Note that the sea level fall of 10 mm/y might correspond to the crustal uplift rate in the 1980's. The two different rate of sea level falling might indicated that the crustal uplift is an intermittent phenomenon.

The period of high local earthquake activity in 1987-1989 around Syowa Station corresponds to the same period when the 10 mm/y sea level fall was obtained. The local earthquake activity must indicate that the crustal uplift occurs intermittently. The crustal uplift occurred during the last few years of the 1980's.

A route for repeated leveling survey was established around Syowa Station in 1979 and 1982. The leveling measurements were repeated in 1996 and 1997 (Kaminuma and Kimura 1997; Kaminuma *et al.* 1997). The observations from the repeated leveling measurements suggest no significant changes, which further supports the idea the crustal uplift is a block movement as proposed Kaminuma and Akamatsu (1992).

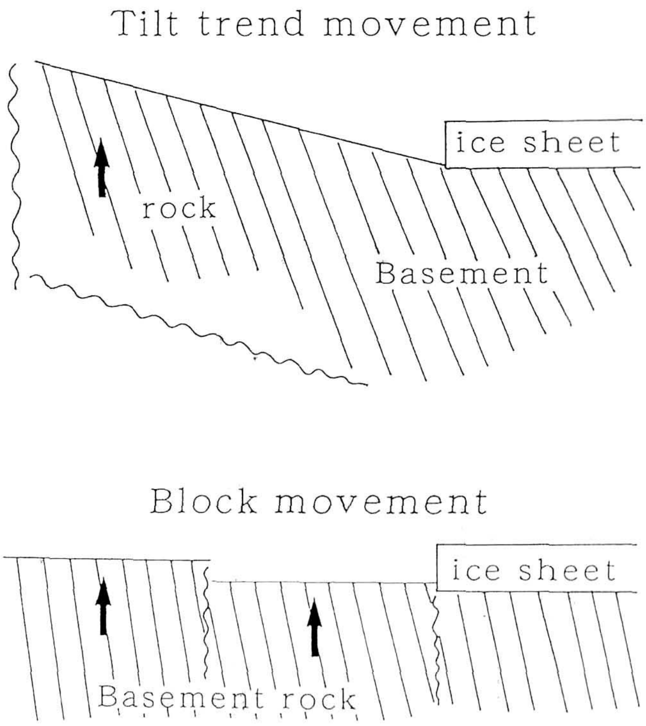

Fig. 4. A scheme of crustal uplift in the coastal area. Tilt trend movement (upper) and block movement (bottom).

Discussion and Conclusion

Crustal movements around Syowa Station are summarized as follows based on the local earthquake activities, oceanic tide, elevated beaches and leveling survey:

1) The elevated beaches around Syowa Station show that the crustal uplift after deglaciation is still going on at present.

2) A trend of sea level falling at a rate of 4.5 mm/y was obtained from the oceanic tide data during 18 years in 1975-1992, and a falling rate of 9.5 mm/y was also obtained from the oceanic tide data during seven years in 1981-1987. These two falling rates indicates that the falling is an intermittent phenomenon.

3) As the locations of epicenters are in the coastal and offshore areas, local earthquakes are inferred to be caused by tectonic stress accumulated by the crustal uplift after deglaciation. The occurrence pattern of local earthquakes is intermittent.

4) The crustal uplift occurs only for a few years during one decade/more, because the occurrence of earthquakes corresponds with the intermittent crustal uplift.

5) As there was no significant height change of leveling during 15 years in 1982-1997, the crustal uplift is a block movement.

6) Estimating from all data mentioned above, the crustal uplift in the Ongul Islands is not a tilt trend movement but represents a block movement as shown in Fig. 4.

If the crustal uplift at a rate of 5 mm/y continues for ten years, the total uplift obtained will be 5 cm. The total amount of the vertical crustal uplift would produce a change of about 15 μGal in gravity. Repeated measurements of absolute gravity over many years might detect the absolute value of vertical crustal movement.

Observations of the oceanic tide, seismic activity and gravity using a superconducting gravimeter (SCG) and LaCoste Romberg gravity meters type D and G are continued at Syowa Station. The crustal uplift after deglaciation continues at present and next intermittent uplift is expected to occur in early of the 2000's. The SCG observation is believed to provide the highest sensitivity and highest resolution data for study of vertical crustal movement. Using the absolute gravimeter together with the

SCG will provide significant insight into the absolute elevation change.

Acknowledgment

The authors expresses their thanks to two conveners of the symposium for giving them the opportunity to present the paper. The manuscript was prepared by Ms. M. Minegishi of National Institute of Polar Research. The authors thanks extend to two anonymous reviewers for their critical reading of the manuscript.

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Received 5 July 1999
Acdepted 1 September 1999