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Article

# Crustal Uplift and Microseismic Activity around Syowa Station, Antarctica

**Katsutada Kaminuma***

*National Institute of Polar Research*
*11-29, Kugenuma-Fujigaya 1, Fujisawa, Kanagawa 251-0031, Japan*

**Abstract :** There is a great deal evidence concerning crustal uplift, after deglaciation, in the vicinity of Syowa Station (69°S, 39°E) from tide gauge data, seismic evidence, raised beaches, marine terraces, etc. The geomorphological and tide gauge data show that the crustal uplift is going on around Syowa Station. Seismic observations at Syowa Station started in 1959. Phase readings of the earthquakes have been published by National Institute of Polar Research once a year since 1968, as one of the Data Report Series. Eighteen local earthquakes were detected on short period seismograms at Syowa Station in 1990-2000. The seismicity during the period from 1990 to 2000 was lower than that from 1987 to 1989 when epicenters of local earthquakes were determined by tripartite seismic array. Local earthquake activity corroborates the crustal uplift, which is an intermittent phenomenon. Sea level falling of 4.5 mm/y was found using data in 1975-1992. This falling rate is consistent with the geomorphological data. A route for repeat leveling survey was established in East Ongul Island. No appreciable change of sea level was observed for the last 14 years. A dynamics of the crustal uplift around Syowa Station has been discussed using geomorphological data, ocean tide, and seismic and leveling data, which 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. Repeated leveling measurements suggest no significant changes, which further supports the idea that the crustal uplift in offshore is not a tilt trend movement but a block movement.

**Key words :** crustal uplift, deglaciation, earthquake, Syowa Station, seismicity.

## 1. Introduction

The Antarctic coastal area and surrounding islands are the places where crustal uplift has occurred after deglaciation. Characterization of crustal movement and estimation of sea level change have been accomplished using a variety of conventional high precision methods such as ocean tide gauge, leveling survey, etc. at Syowa Station (69°S, 39°E) which is located on East Ongul Island in Lützow-Holm Bay, East Antarctica. Kaminuma (1996) summarized a process of crustal uplift around Syowa Station. To detect crustal movement around Syowa Station, a leveling survey was established on East Ongul Island in 1982, and repeated measurements over the route were done in 1992, 1996 and 1997. However there was no significant height change of leveling around Syowa Station during 14 years (Kaminuma and Kimura 1997).

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

Kaminuma and Kanao (1998) and Kaminuma *et al.* (1998) summarized the local earthquake activity around Syowa Station. Nine local earthquakes were detected from waveforms on short period seismograms at Syowa Station in 1990-1996. Another local event was detected in 1997. The local seismicity in 1990-1997 was very low 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). A few local earthquakes were detected on the seismogram at Syowa Station every year during 1998-2000.

*Corresponding author. E-mail : katsu-3@nifty.com

In this paper, a relation between crustal uplift and microseismic activity around Syowa Station is discussed and reviewed using the geomorphological data, oceanic tide, and seismic and leveling data.

## 2. Crustal uplift

Raised 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 the past glaciation is observed around Syowa Station: erratic boulders, glacial scour and various glacial deposits can be found in the snow free area. Shell fossils have been found on the raised beaches around Syowa Station and the fossils were dated to be 5000-6000 B.P. Many raised beaches and marine terraces are recognized around Syowa Station. Miura *et al.* (1998) summarized raised beach deposit around Lützow-Holm Bay in a geomorphological view. A view of the raised beach is shown in Fig. 1. The maximum height of the raised beaches is about 20 m. The uplift rate of the raised beaches is estimated to be 3-6 mm/y from the geomorphological data.

The raised beaches indicating the crustal uplift are a reflection of the regional isostatic rebound. The Antarctic ice sheet still extends to the coastal areas at present. However, crustal uplift coincident with deglaciation appears to be continuous since Holocene (Yoshida and Moriwaki 1979).

Two sea level falling rates at Syowa Station were obtained using tide gauge data. Odamaki *et al.* (1991) obtained a trend of sea level falling at a rate of 9.5 mm/y from 1981 to 1987. Michida *et al.* (1995) estimated the mean sea level change at Syowa Station using the data collected during 18 years from 1975 to 1992. They obtained a trend of sea level falling at a rate of 4.5 mm/y. This sea level change was measured relative to the land-based benchmark on East Ongul Island. Considering the rise of global mean sea level at the rate of 1-2 mm/y (Warrick 1993), the falling rate of mean sea level at Syowa Station should be over 10 mm/y.

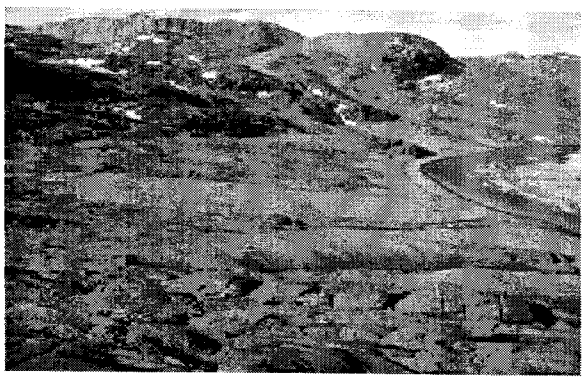

**Fig. 1. A picture of raised beach, Kizahashi Beach in Skarvsnes, Lützow-Holm Bay. The step-like topography is recognized. Photographed by H. Miura at National Institute of Polar Research.**

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 beaches. The uplift rate of the raised 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 geomorphological 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. Two different rates of sea level fall may indicate 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 be an indication that the crustal uplift occurs intermittently. Most of the crustal uplift occurred during the last few years of the 1980's.

A route of 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 repeated leveling measurements suggest no significant change, which further supports an idea that the crustal uplift is a block movement as proposed by Kaminuma and Akamatsu (1992).

## 3. Local earthquakes

No large earthquakes of magnitude greater than 5 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 (Kaminuma 1994). 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

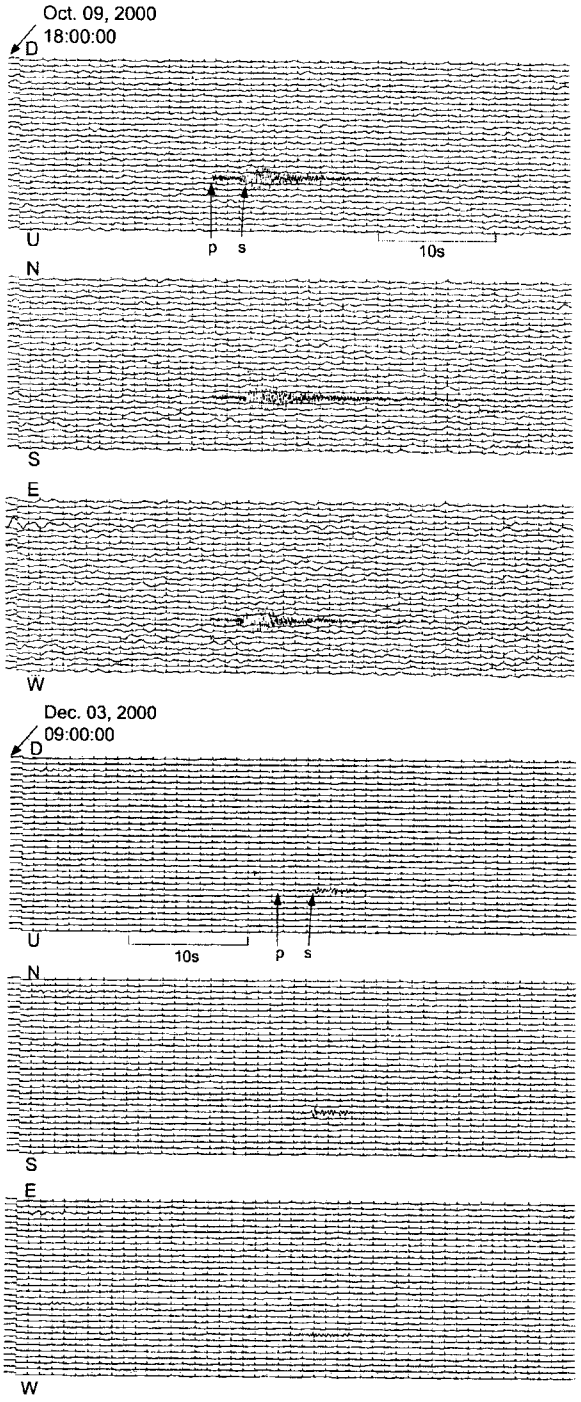


**Fig. 2. A three-component seismogram of local earthquakes recorded by STS seismographs at Syowa Station: a) the event on October 09, 2000 and b) the event on December 3, 2000.**

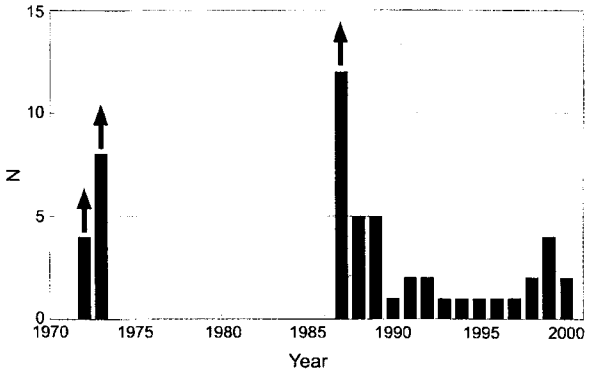


**Fig. 3. Annual numbers of local earthquakes around Syowa Station. Arrows indicate that the actual number of earthquakes must be more than those shown in the figure.**

from June 1987 to October 1989 (Akamatsu *et al.* 1988, 1989).

Attempts were made to locate earthquake epicenters of the local events using the first particle motion to 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. P-S times 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. Four local events were located in the area where local earthquakes in 1987-1989 had been located. Two local events were also detected on seismograms at Syowa Station in 1998 and 2000, and four events in 1999. The P-S times of the eight micro earthquakes are less than 10s. The three-component seismograms of the two events in 2000 are shown in Figs. 2a and b. Fig. 3 shows the annual number of local earthquakes in the vicinity of Syowa Station detected from the three-component short period seismographs. The arrows indicate that the actual number of earthquakes is more than that in the figure because the observation period was less than 12 months.

The seismicity in 1998-2000 seems to be a little higher than that in 1990-1997. However, the annual number of the earthquakes occurred in 1987-1989 is larger than 5. Therefore the seismic activity in 1998-2000 is still not so high as that in 1987-1989 when the seismic activity was the highest since 1970.

Kaminuma and Akamatsu (1992) suggested a process for the local earthquake activity in the vicinity of Syowa Station as follows:

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

2) The rate of stress accumulation is very small so that only small, micro/ultra-micro earthquakes with magnitude less than 3 occur in the margin of the continent and offshore.
3) The crustal uplift occurs only for a few years in a decade or more. The occurrence of earthquakes corresponds to the intermittent crustal uplift.

## 4. Discussion and conclusion

Crustal movements around Syowa Station are summarized as follows based on the local earthquake activities, ocean tide, raised beaches and leveling survey (Kaminuma 1996).

1) The raised beaches around Syowa Station show that the crustal uplift after glaciation is still going on at present.
2) A trend of sea level fall at a rate of 9.5 mm/y was observed using tide gauge data in 1981-1987 and at a rate of 4.5 mm/y during 18 years from 1975 to 1992. These two fall rates indicate that the falling is an intermittent phenomenon.
3) As the locations of epicenters are in the margin of the continent and offshore, 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 in a decade or more, because the occurrence of earthquakes corresponds to 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) From all data mentioned above, it is estimated that the crustal uplift in the Ongul Islands is not a tilt movement as shown in Fig. 4.

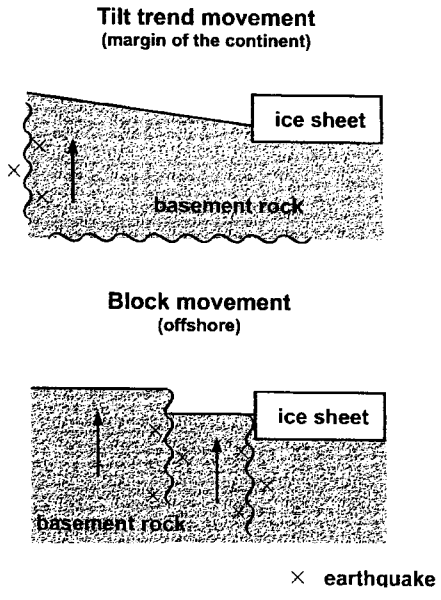


**Fig. 4. A scheme of crustal uplift. Tilt movement at continental margin and block movement in offshore.**

However, the view of raised beaches in Fig. 1 suggests that the crustal uplift in Skarvsnes, a margin of the continent is a tilt movement. It is, therefore, concluded that the crustal uplift at continental margin is a tilt movement and that at offshore as the Ongul Islands is 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 $\mu$Gal in gravity. Repeated measurements of absolute gravity over many years might detect the absolute value of vertical crustal movement.

The ocean tide, seismic activity and gravity using a superconducting gravimeter (SCG) and LaCoste-Romberg gravity meters type D and G have been continuously observed at Syowa Station. The crustal uplift after deglaciation continues at present and next intermittent uplift is expected to occur in the early 2000's. The SCG observation is believed to provide the data of the highest sensitivity and resolution to study vertical crustal movement. Using the absolute gravimeter together with the SCG will provide significant insight into the absolute elevation charge.

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